

Exploration of Heat Strain during Light to Moderate Intensity Exercise throughout
Pregnancy

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Thesis submitted to
The Faculty of Graduate and Postdoctoral Studies
University of Ottawa
In partial fulfillment of the requirements for the master's degree in the
School of Human Kinetics

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Abstract

Regular physical activity is recommended in healthy pregnancies and has been shown to mitigate adverse pregnancy outcomes. Despite the benefits, many women do not adhere to the recommendations due to concerns of exercise-induced heat stress and the dangers it could pose to the developing fetus. While the majority of the concerns raised are not grounded in evidence, currently there are no studies that directly examine the isolated influence of pregnancy on metabolic heat production resulting from physical activity. Additionally, despite the prevalent use of psycho-physical tools in clinical settings, there is a scarcity of literature exploring the relationship between the physiological and perceptual measures of exercise-induced heat strain in the pregnant population. Therefore, objective one of this thesis was to quantify the heat production resulting from light to moderate physical activity (intensities recommended during pregnancy) throughout gestation. Secondly, in objective two, physiological and perceptual measures of thermal strain were compared and assessed throughout pregnancy. In evaluating the change in heat production resulting from exercise (objective one), 10 non-pregnant control (30 ± 1 yrs; $\text{BMI} = 22.3 \pm 0.8 \text{ kg/m}^2$) and 10 pregnant (32 ± 1 yrs; pre-pregnancy $\text{BMI} = 22.8 \pm 0.8 \text{ kg/m}^2$) women performed a seven stage submaximal walking test in a thermal controlled chamber (23°C). Testing was performed during their 1st (T1, 12-16 wks), 2nd (T2, 24-28 wks) and 3rd (T3, 34-38 wks) trimester of pregnancy while metabolic heat production was measured through indirect calorimetry. To assess the changes in thermal and perceptual strain (objective two), 16 non-pregnant control (32 ± 1 yrs; $\text{BMI} = 22.7 \pm 0.7 \text{ kg/m}^2$), and 20 pregnant (32 ± 1 ; pre-pregnancy $\text{BMI} = 23.2 \pm 0.6 \text{ kg/m}^2$) women underwent a graded walking exercise protocol at T2 and T3. Over the course of this test, heart rate, tympanic temperature (T_{tymp}), skin temperature (T_{skin}), rate of perceived exertion (RPE, 20-point scale) and thermal sensation (9-point scale) were assessed.

Findings from this thesis show that for the same given progressive exercise test, women in T1 experienced similar metabolic heat production to their non-pregnant counterparts. However, as pregnancy progressed, women exhibited on average, a 7-8% increase in heat production per trimester of pregnancy that can be accounted for by weight gain. Further, at baseline conditions, heart rate responses increased with pregnancy, while T_{tymp} remained unchanged and T_{skin} decreased. In response to exercise, the magnitude of change in heart rate, T_{tymp} and T_{skin} did not differ between gestational conditions. Finally, a strong correlation was identified between heart rate and RPE throughout pregnancy, while thermal sensation only directly correlated with T_{tymp} and not T_{skin} . Overall, the present findings suggest that while the same progressive exercise test results in greater levels of heat production as pregnancy progresses, this is not observed in physiological or perceptual measures of heat strain. Rather, findings of this thesis support the notion of improved thermoregulatory responses to account for the increase in metabolic heat production. Moreover, the present thesis provides support for the use of the RPE and thermal sensation scales as effective psycho-physical tools in the pregnant population under conditions of light to moderate exercise in normothermic conditions.

Acknowledgements

I would like to begin by thanking the two individuals who made this experience possible. Drs. Kristi Adamo and François Haman, you propelled me forward with guidance and support and provided me room to grow. Your passion and dedication to the field has helped me develop a continued appreciation for research and a lifelong pursuit of knowledge. I would also like to extend my appreciation to Drs. Éric Doucet and Michael De Lisio for helping navigate this thesis in the right direction over past year. Not to be forgotten, I am grateful for all those who mentored me throughout my academic growth and the lab mates who made coming to the lab every morning so enjoyable. Finally, this study would not have been possible without the involvement of the many researchers, coordinators, research institutions, hospitals and wonderful volunteers who were integral to its success.

The journey through my Masters was not one that I could have completed alone. And so, I'd like to take the opportunity to duly acknowledge those who played a significant part along the way. Sheila and Kat, you ladies were both by my side through different legs of this marathon and through it all you were more than friends. From the early morning trials, to the late-night writing sessions, you were a shoulder to lean on, a voice of encourage through the hurdles and a helping hand on countless occasions. I knew that I would meet many new faces along the way, but I never expected to meet such strong, genuine and admirable women that I am proud to call, and what I can only hope to be, lifelong friends. To Kat, a special thank you for your partnership throughout this study and your kindness outside of it. Eric and Melany, thank you both for keeping me laughing and sharing with me your optimism when mine ran low.

Above all else, I would like to express my profound gratitude to my mother and sister. Thank you for your unfailing love and support in every step of my growth. You have taught me to be resilient, compassionate, and patient. You nurtured in me the confidence to succeed in the face of failure. You are my source of inspiration and the proof I need that women can achieve anything they set their minds to. For this and so much more, I would like to dedicate this thesis to you.

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Abbreviations

\dot{C}	Convective heat loss
\dot{C}_{res}	Convective heat loss through respiration
CON	Control
K	Conductive heat loss
\dot{E}_{max}	Rate of maximal heat loss
\dot{E}_{req}	Rate of evaporative requirement
\dot{E}_{res}	Evaporative heat loss through respiration
GWG	Gestational weight gain
H_{prod}	Metabolic heat production
\dot{H}_{prod}	Rate of metabolic heat production
HR	Heart rate
i_m	Water vapor permeability coefficient
I_T	Insulative value of the clothing
LR	Lewis Relation
\dot{M}	Metabolic rate (Watts)
P_a	Vapor pressure of ambient water
PA	Physical activity
P_{sk}	Vapor pressure of saturated skin
\dot{R}	Radiative heat loss
REE	Resting Energy Expenditure
RPE	Rate of perceived exertion
SE	Standard error
T1	Trimester 1: between 12-16 wks gestation
T2	Trimester 2: between 24-28 wks gestation
T3	Trimester 3: between 34-38 wks gestation
T_{core}	Core body temperature
T_{tymp}	Tympanic temperature
T_{skin}	Skin Temperature
\bar{T}_{skin}	Mean skin temperature
TS	Thermal Sensation
$\dot{V}O_2$	Rate of oxygen consumption
$\dot{V}CO_2$	Rate of carbon dioxide production
W	Work (kcal)

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Chapter 1: Introduction

Over the past decade, there has been a growing body of research showing the benefits of engaging in aerobic and strength training exercises throughout uncomplicated pregnancies for not only the health of the mother but also the developing fetus (Committee on Obstetric Practice, 2002). Improved management of gestational weight gain (GWG), and lowering the risk of preeclampsia, and pre-term delivery (Barakat et al., 2016; Davies, Wolfe, Mottola, & MacKinnon, 2003; Mottola et al., 2018; Wiebe, Boulé, Chari, & Davenport, 2015) are among the benefits associated with an active lifestyle during pregnancy. Despite the growing evidence supporting physical activity (PA) throughout gestation, we know that the majority of women fail to meet these recommendations (Evenson & Wen, 2011; Santo, Forbes, Oken, & Belfort, 2017) and reports indicate this may be related to women choosing not to engage in, or withdraw from exercise for fear of overexertion or overheating (Franklin, Mishtal, Johnson, & Simms-Cendan, 2017). The noted fear surrounding heat illustrates the need for more evidence-based research examining the absence of heat-related risks resulting from exercise in this population. Accordingly, investigating the safety parameters around common modes of PA, such as walking, and its influence on pregnancy-related health outcomes is crucial to confidently encourage more women to partake in PA over the course of their pregnancies. Accordingly, this review will examine the physiological changes associated with pregnancy and responses to exercise and exercise related heat stress in both the pregnant and non-pregnant populations.

1.1 Human Pregnancy: Physiological & Anatomical Changes

Over the 40 weeks of human pregnancy, the maternal body undergoes substantial changes to support fetal growth and development. The myriad of physiological and anthropometric changes include, but are not limited to, increase in respiratory exchange, increase in blood volume, hormonal shifts, and the production of new tissue. Moreover, pregnancy is accompanied by weight gain, shifts in weight distribution and alterations in skeletal and musculoskeletal form and function; all of which affect daily activities.

In the relatively short duration of pregnancy, the maternal blood volume increases up to 50% (San-Frutos et al., 2005) which results in the decrease of haemoglobin concentration and red blood cell count (Soma-Pillay, Nelson-Piercy, Tolppanen, & Mebazaa, 2016). Within the vasculature, peripheral resistance is reduced, and active vasodilation is increased early in pregnancy through increased nitric oxide and estradiol bioavailability (Soma-Pillay et al., 2016). To counteract the drop in systemic vascular resistance, cardiac output increases by up to 40% driven by increases in blood volume (Chesley, 1972; Hall, George, & Granger, 2011; Hytten & Paintin, 1963), stroke volume and heart rate (HR) (Hall et al., 2011; Robson, Hunter, Boys, & Dunlop, 1988). In fact, increases in HR of 10-20 bpm are maintained throughout pregnancy (San-Frutos et al., 2005).

Compared to pre-pregnancy levels, the surge in tissue formation, as well as the metabolic activity of the fetus, results in a 15-29% increase in resting energy expenditure (REE) by the third trimester (Kopp-Hoolihan, van Loan, Wong, & King, 1999; Löf, 2011; Soma-Pillay et al., 2016). The metabolic shift associated with pregnancy is also accompanied by many anatomical changes that directly influence the body's physical structure and thus bear upon movement mechanics over the 40 weeks. In particular, pregnant females experience a gradual increase in body weight. While guidelines such as that of the Institute of Medicine (Gilmore et al., 2016) provide recommendations

on healthy GWG, a thorough understanding of the composition of this weight remains a challenge given the limitations surrounding imaging in pregnancy. The inability to accurately examine human development throughout term has led to controversy in the literature and thus we only have theoretical models of estimating energy requirements and distribution (Pitkin, 1976). We do know, however, that the increase in weight can be accounted for by not only the growing fetus and maternally developed life supporting tissues, but also by increased fat stores in the mother (*Weight Gain During Pregnancy*, 2009). Total increase in fat storage varies between individuals and depends on factors of food intake, PA and pre-pregnancy body composition. As maternal weight progressively increases, in turn, the physical load on the body increases creating a physiological strain that requires accommodations in daily life and PA through alterations in skeletal and musculoskeletal form and function. Such alterations include lumbar lordosis (Franklin, Conner-Kerr, & Pt, 1998) and a forward shift in the centre of gravity (Fries & Hellebrandt, 1946) which progressively develop in the later stages of pregnancy and consequently impact movement and locomotion patterns and strategies.

1.2 Exercise during Pregnancy

While historical beliefs encouraged women to reduce their workload throughout pregnancy and refrain from engaging in PA to mitigate adverse pregnancy outcomes, current guidelines promote a far more active gestation. Today, guidelines supported by recent evidence recommend that all women with uncomplicated pregnancies partake in aerobic and strength conditioning exercises throughout pregnancy (Committee on Obstetric Practice, 2002; Ehrlich et al., 2016). Benefits resulting from a physically active lifestyle during gestation include better management of gestational weight gain, and lowering the risk of adverse health outcomes including gestational

diabetes, preeclampsia, and pre-term pregnancy (Barakat et al., 2016; Davies et al., 2003; Mottola et al., 2018; Wiebe et al., 2015).

Despite the overwhelming benefits of PA to the mother and fetus, only 9-15% of women meet the current recommendations (Evenson & Wen, 2011; Santo et al., 2017). Further, only 61% of women report engaging in any form of PA and a mere 16% of those inactive before conception initiate PA during their pregnancy (Ning et al., 2003). While the reasons behind such low adherence rates are not completely understood, education and income have been identified as barriers to participating in exercise for some expectant mothers (Ning et al., 2003). Additionally, other women attribute not exercising to fear of overexertion and overheating that may pose risks to the fetus (Franklin et al., 2017).

In Evenson's 2014 (Evenson et al., 2014) review of international exercise guidelines for pregnancy, Australian and Norwegian recommendations were found to warn against excessive body heat. Specifically, the 2002 ("SMA statement the benefits and risks of exercise during pregnancy," 2002) and the more recent 2016 (Hayman Mel & Brown, 2016) Australian guidelines recommend avoiding activities that may result in early exposure to high core body temperature (T_{core}) during pregnancy however fail to provide quantifiable values of potentially dangerous conditions. Similarly, Canadian guidelines precaution against PA in excessive heat and high humidity (Mottola et al., 2018). Thus, whereas governing health bodies recognize the potential for heat-related adverse pregnancy outcomes, few guidelines around the world provide concrete recommendations regarding modes of exercise or intensity for stopping parameters such as absolute (e.g. HR) or relative (e.g. rate of perceived exertion: RPE) indicators (Evenson et al., 2014).

1.3 Heat Strain Resulting from Exercise

A rise in maternal T_{core} has long been considered a danger to pregnancy outcomes (Erickson, 1991; Miller, Smith, & Shepard, 1978; Smith, Clarren, & Harvey, 1978). This notion stems from the understanding of the temperature gradient between the maternal body and that of the placenta and fetus. In a normal pregnant state, the fetal temperature is 0.5°C higher than that of maternal T_{core} (Abrams, Caton, Clapp, & Barron, 1970). It is this gradient that allows for heat produced to dissipate away from the fetus to the mother who can then eliminate the heat through heat loss avenues with the environment. Concerns arise in situations where maternal temperature increases such that the fetal-maternal gradient is reduced or reversed. This would require significant elevations in T_{core} or attenuations in heat loss responses. Much of the literature examining such cases are those of animal models which have linked maternal hyperthermia to elevated risks of fetal demise including embryonic death, congenital malformations and abortions (Edwards, 1968, 1969). However, in these studies hyperthermia was induced by elevating T_{core} $4\text{-}5^{\circ}\text{C}$ above baseline measures; T_{core} changes that would be outside physiological limits in humans. Human epidemiological data have also shown associations between high fever, resulting from infections, and neural tube defects (Shiota & Opitz, 1982). To better evaluate and assess the potential impact of exercise and heat stress on the pregnant population, it is vital to first recognise thermoregulatory responses to PA in the non-pregnant state.

During locomotion and exercise, the human body can reach a mechanical efficiency of 30% (Cavagna & Kaneko, 1977). The relative inefficiency of the human body as a mechanical system results in heat as a by-product (metabolic heat production, H_{prod}) that is released into the body and subsequently the environment. Internally, H_{prod} is a consequence of metabolic reactions and is vital in supporting T_{core} regulation. During exercise, H_{prod} is quantified as the difference between

metabolic rate (\dot{M}) and external work (W) (Kenny & Jay, 2013). As a result of exercise and the increase in H_{prod} , T_{core} passively rises (Davies, 1979; Nielsen & Nielsen, 1965). If not adequately addressed through heat loss responses, T_{core} can continue to climb and can lead to a state of hyperthermia and potentially heat injury. In the healthy state, once a temperature threshold (set point) is met, the human body reacts to increases in T_{core} by increasing blood flow to the skin, and sweating which together represent the primary means of heat loss in humans (Charkoudian, 2003). Heat dissipation is initiated at the temperature sensitive neurons in the preoptic area of the anterior hypothalamus in reaction to increased neuronal temperature (Boulant, 2000, 2006) and skin temperature (T_{skin}) (Boulant & Gonzalez, 1977; Charkoudian, 2003). Consequently, cholinergic nerve co-transmission stimulates the active vasodilatory system to augment skin blood flow (Charkoudian, 2010; Kellogg et al., 1995). Heat is then transferred from the core, through blood circulation, towards the surface of the skin allowing conductive heat transfer between the skin and ambient air driven by the difference in temperature gradient (Kenny & Jay, 2013). In conjunction, sympathetic cholinergic nerve activation stimulated by increased T_{core} facilitates sweating and allows for heat dissipation through evaporative heat loss (Kenny & Jay, 2013). These heat loss mechanisms cooperate to counterbalance the heat load on the body with the aim of establishing a reduction or plateau in T_{core} . In situations where heat loss responses cannot sufficiently counteract the heat load, T_{core} continues to rise and results in increased heat storage (S). S is defined by the following equation (Kenny & Jay, 2013):

$$S = H_{prod} + (H_{dry} + H_{evap} + H_{resp})$$

Where heat storage is the sum of H_{prod} and the body's heat loss responses through dry, evaporative, and respiratory heat exchange (H_{dry} , H_{evap} and H_{resp} , respectively). H_{dry} is the combination of convective, conductive and radiative heat exchange and is primarily manifested in

skin blood flow responses. Conversely, H_{evap} is the result of sweating mediated through the difference in partial pressure of water vapor in ambient air and that of sweat on the skin surface. Finally, H_{resp} is the result of the heat transfer to the inspired air during the saturation process of the gases as they enter the nasal passage. The moisture retention of the gases allow heat to be transferred to the respired air and expelled from the body through exhalation.

When the rate of cooling required by the body through evaporative heat loss (\dot{E}_{req}) is greater than the maximal evaporative capacity of the environment (\dot{E}_{max}), heat stress becomes uncompensable (Givoni & Goldman, 1972). \dot{E}_{req} is expressed as follows:

$$\dot{E}_{\text{req}} = \dot{H}_{\text{prod}} \pm (\dot{C} + \dot{R} + \dot{K}) \pm (\dot{C}_{\text{res}} - \dot{E}_{\text{res}})$$

and is calculated as the summation of the rate of metabolic heat production (\dot{H}_{prod}) and the rate of heat loss being eliminated through radiative (\dot{R}), conductive (\dot{K}) and convective (\dot{C}) heat loss as well as the difference between the convective (\dot{C}_{res}) and evaporative (\dot{E}_{res}) heat transfer through respiration (Cheung, McLellan, & Tenaglia, 2000). Conversely, \dot{E}_{max} is expressed as:

$$\dot{E}_{\text{max}} = LR \cdot i_m / I_T \cdot (P_{sk} - P_a)$$

and is calculated as the product of the Lewis relation (LR, 16.5°C/KPa), water vapour permeability coefficient (i_m), the insulative value of the clothing being worn (I_T), and the difference in saturated skin vapor pressure (P_{sk}) at mean T_{skin} the ambient water vapor pressure (P_a) (Gonzalez, McLellan, Withey, Chang, & Pandolf, 1997).

As depicted through the calculations of \dot{E}_{req} and \dot{E}_{max} , an uncompensable heat situation can be a result of the environment, the activity, or a combination of the two. In addition, conditions such as neuropathies, impaired cutaneous vasodilation and sudomotor dysfunctions (such as those found in some disease states including diabetes or in recipients of skin grafts) can also influence thermoregulatory capacity (Crandall & Davis, 2010; Davis et al., 2007; Rutkove et al., 2009).

Moreover, Cheung's review (Cheung et al., 2000) of the thermophysiology behind uncompensable heat stress highlighted that physiological changes and physical characteristics also influence how well humans can withstand thermal stress. Of particular interest, multiple studies have demonstrated that higher aerobic fitness resulting from habitual training is associated with improved tolerance of uncompensable heat stress conditions and may be a consequence of reduced cardiovascular strain (Cheung & McLellan, 1999; Piwonka & Robinson, 1967). Likewise, body composition is known to impact temperature regulation. Specifically, the influence of body fat on heat storage lies in the specific heat of fat mass ($1.68 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{C}^{-1}$) compared to that of fat-free mass ($3.36 \text{ kJ} \cdot \text{kg}^{-1} \cdot \text{C}^{-1}$) (Anderson, 1999). Heat capacity between the two tissue types differs by a factor of two indicating that for a given heat load per kilogram of body weight, an individual with greater fat composition will experience a more pronounced increase in T_{core} (Anderson, 1999; Haymes, McCormick, & Buskirk, 1975). In accordance, individuals with higher body fat percentages have shorter heat tolerance times (McLellan, 1998). In the context of pregnancy, such information would suggest that as women gain more fat with each trimester, they are reducing their heat tolerance for the same activities.

Despite the abundant literature available in the field of exercise thermoregulation, there is only limited research examining the role of exercise-induced heat stress in pregnancy. Further still, while the potential for hyperthermia is understandable at high intensity and maximal workloads, there are very few studies examining submaximal exercise, an intensity more representative of PA in the average population. Among studies investigating exercise during pregnancy, Clapp (1991) examined thermoregulation through changes in T_{core} in response to 20-min of moderate-intensity-exercise in aerobically conditioned recreational female athletes before and during pregnancy. Their findings indicated a drop in resting, as well as maximal T_{core} as gestation progressed; findings

which were later supported by Lindqvist (2003) and Hartgill (2011). In addition, Clapp (1991) demonstrated that the onset of sweating shifted to lower T_{core} set points with gestation. These findings suggest an altered thermoregulatory response throughout pregnancy that may promote heat loss and protect against the risk of overheating. In contrast to Clapp's findings, Jones and colleagues (Jones, Botti, Anderson, & Bennet, Nancy L. RN, 1985) observed no differences in T_{core} responses throughout pregnancy in response to moderate and high-intensity treadmill running in aerobically conditioned pregnant women. These authors did, however, observe an increase in resting T_{skin} with the progression of each trimester, which supports an increased drive for heat dissipation.

Most recently, Ravanelli *et al.*(2018) examined 12 studies exploring exercise during pregnancy in a systematic review to outline exercise parameters for pregnant women wherein T_{core} would not exceed teratogenic thresholds. Among the exercise limits that would not pose a risk to the maternal or fetal systems were land-based exercises lasting for up to 35 min at intensities up to 80-90% of HR_{max} in environmental conditions of 25°C and 45% relative humidity. In the context of current Canadian PA guidelines (Davies *et al.*, 2003), the PA recommendations for pregnant women (65-75% of HR_{max}) are well within these parameters. Overall, the literature supports the notion that light to moderate exercise intensities do not induce enough heat stress to provoke a risk to fetal health (Clapp, 2006; Ravanelli *et al.*, 2018). Despite this, no study has yet quantified the underlying change in H_{prod} associated with the progression of pregnancy in the most basic activities. Obtaining a measure of change in metabolic heat production associated with gestation would establish a value from which furthermore research and guidelines can be developed for varying environments and exercise conditions.

1.4 Perceptions of Exercise and Heat Strain

Within clinical and laboratory settings, psycho-physical tools such as the RPE scale are widespread and commonly used given the strong evidence supporting their efficacy across sex and age groups (Balasekaran, Loh, Govindaswamy, & Cai, 2014; Gros Lambert & Mahon, 2006; Penko, Barkley, Koop, & Alberts, 2017; Zamunér et al., 2011). However, while psycho-physical tools are also used and prescribed among the pregnant population (Committee on Obstetric Practice, 2002) there is little research examining their validity throughout gestation. Given that pregnancy is characterized by a multitude of physiological and anatomical changes that are continually shifting over the three trimesters, the female body takes on unique individual profiles at each stage. As such, it is valuable for all those who work with the pregnant population to consider how compatible such tools are with the changing physiological demands across gestation.

Indeed, in the non-pregnant population, the role and validity of perceptual information have been heavily investigated. At present, it is generally accepted that the integration and interaction of physiological and perceptual information govern behaviours and allow the modification of activities to prevent hyper- or hypothermia, ultimately mitigating the risk of injury. Further, perceptual information resulting from PA has long been considered an indicator of the summation of physiological strain (Borg, 1982). As a result, RPE scales have extensively been used as a psycho-physical tool in clinical and research settings given their feasibility and convenience. Today, the BORG scale, one such RPE scale, is considered a reliable indicator of physiological strain due to its strong correlation with HR during a variety of exercise tasks (Borg & Linderholm, 2009; Scherr et al., 2013).

Despite the acceptance of psycho-physical tools such as the BORG scale, the mechanisms of the body's physiological and perceptual responses are often investigated independently of one

another. For example, the peripheral fatigue model suggested that fatigue arises solely in response to muscle contraction failure due to lactic acid build up (Hill & Lupton, 1923). Likewise, in an excerpt from *Biochemistry of Exercise* (Knuttgen, Vogel, & Poortmans, 1983), Richard Edwards introduced the catastrophe model wherein he suggested that the only factors mediating fatigue were the human body's physiological and biomechanical limits. These unidirectional approaches to investigating physiological limits fail to recognize the interplay between physiological and perceptual information. In 2006, Tucker and colleagues (2006) introduced a unique method for understanding the role of perceptual information resulting from environmental cues in governing physical activity pace and the resulting physiological responses. The method, termed 'RPE clamping', involves participants cycling at a constant RPE in three different environmental conditions (15, 25 and 35°C) by self-adjusting their exercise pace and therefore power output (Tucker et al., 2006). Tucker's results showed that to maintain the set RPE, work load was significantly reduced in the 35°C condition, ultimately reducing the amount of heat storage and allowing T_{core} to remain similar between all three temperature conditions. Based on their findings, Tucker and colleagues concluded that RPE plays an important anticipatory role in the regulation of exercise intensity and, ultimately, physiological responses. The idea of an anticipatory feedback model was later introduced by Tucker (2009) and is highlighted in Figure 1. In stark contrast to the fatigue model, or Edwards' catastrophe model, the anticipatory feedback model highlights the complexity of exercise regulation and the fact that physiological changes are not the only cues mediating exercise performance.

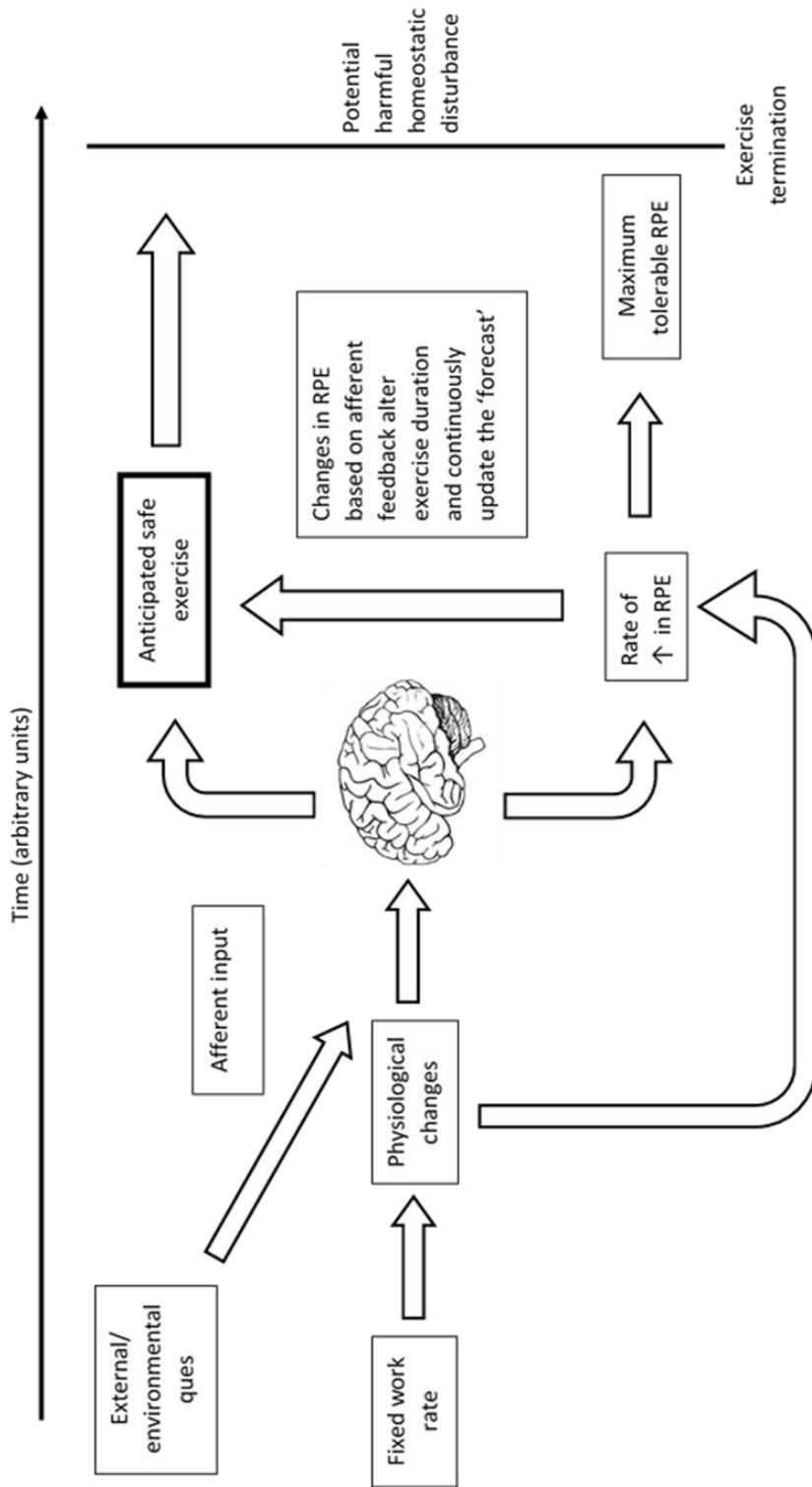


Figure 1. Anticipatory Feedback Model: regulation of exercise performance with input from external cues and Rate of perceived exertion (RPE). Figure modified from Tucker, 2009

Such concepts are not unfamiliar to the pregnant state. In fact, in line with the notion that protective mechanisms may be in place in the central nervous system to guard against and prevent hyperthermic events in pregnancy, examination of gait patterns have identified a trade-off in energy efficiency for increased safety. Specifically, Wall-Scheffler and Myers (2013) observed that individuals carrying loads representative of 3rd trimester pregnancy chose a self-selected walking rate 5% slower than their non-load bearing counterparts in a walking task. The authors attributed their findings to the possible heat load sensitivity of women during the pregnant state and suggested that during such tasks, the body favours locomotion patterns that reduced heat generation and energy consumption. Overall, the findings of Wall-Scheffler and Myers also supported those of Tucker in the notion that psychological cues influence locomotion behaviours in order to mitigate risk of overheating. With that being said, to date, there is a scarcity of direct evidence examining the validity of the psycho-physical tools in the pregnant population, and within these studies, there are conflicting results. Pivarnik (1991) demonstrated that HR and corresponding RPE responses remained constant throughout gestation in response to a treadmill and cycling ergometer test. In 1992, O'Neill and colleagues investigated the correlation between HR and RPE in response to weight bearing and non-weight bearing aerobic tests for women in the 2nd and 3rd trimester as well as postpartum (O'Neill, Cooper, Mills, Boyce, & Hunyor, 1992). In contrast to Pivarnik's findings, O'Neill identified that the correlation between the two variables was insignificant during pregnancy such that RPE scales underestimated HR. The disparity in the literature supports the need to further study these relationships with more scrutiny.

While RPE scales are among the most common in the field of exercise, another important psycho-physical tool in the context of heat strain is the thermal sensation (TS) scale. The best of our knowledge, no study has directly investigated the correlations between physiological

parameters to that of TS in pregnant women. Even in non-pregnant populations, TS has not been investigated to the same extent as RPE scales. In 1974, Kamon et al. were the first to extensively investigate the relationship between TS and the physiological measures of heat strain (Kamon, Pandolf, & Cafarelli, 1974). Measures of HR, oxygen uptake, T_{skin} and T_{core} were monitored at different exercise intensities and ambient room temperatures ranging between 40-70% and 24-54°C, respectively. Kamon and colleagues identified a strong correlation between TS and the responses of HR and T_{skin} . Given that T_{skin} is a reflection of ambient temperature, a response that had been previously observed by Gagge and colleagues (1967), Kamon ascribed the association between TS and T_{skin} as a means by which the body assesses the environment. Accordingly, it is now generally accepted that environmental conditions such as temperature have a profound impact on exercise performance such that, relative to cooler environments, exercise at higher temperatures increases cardiovascular and thermal strain and provokes a higher RPE (Maw, Boutcher, & Taylor, 1993). In contrast to the responses of T_{skin} , Kamon et al. (1974) found no association between TS and T_{core} despite the increase in both measures at the end of the exercise tasks. While the reasons behind the lack of association were not explored by Kamon, one explanation for the findings may be the body's tight regulation of T_{core} resulting in relatively minute changes in comparison to the large variability in TS resulting from the various temperature conditions and exercise stimuli.

Independent of environmental conditions, higher $\dot{V}O_{2\text{max}}$ has been shown to result in higher T_{core} tolerance regardless of hydration, heat acclimation status or adiposity (Cheung & McLellan, 1998; Selkirk & McLellan, 2001). In line with these findings, trained athletes consistently underestimate their physiological strain during exercise-induced heat stress (Tikusis, McLellan, & Selkirk, 2002). Cheung proposed that psychological interventions and techniques may account for what appears to be a disconnect in the physiological and perceptual information among athletes

and trained individuals (Cheung, 2010). In line with this notion, hypnosis has been shown to improve tolerance of heat-pain (Langlade, Jussiau, Lamonerie, Marret, & Bonnet, 2002), and psychological skills training has proved beneficial in improving exercise performance in the heat (Barwood, Thelwell, & Tipton, 2008).

Based on the current literature, it is evident that the interplay between physiological cues and perceptual sensations is complex and multifaceted. Given the potential value of the TS scale in assessing safety limitations in different populations including pregnant women during PA, preliminary investigation is needed to evaluate the interactions and accuracy throughout gestation.

1.5 Objectives and Hypotheses

This thesis sought to build on the available literature by exploring physiological and perceptual variables during light to moderate exercise in the 1st, 2nd and 3rd trimester of pregnancy. Specifically, the objectives of this thesis are:

1. To quantify the change in metabolic heat production over the course of pregnancy for a constant exercise protocol.
2. A) To quantify the changes in physiological (heart rate, tympanic temperature and mean skin temperature) and perceptual measures (rate of perceived exertion and thermal sensation) of exertional and thermal strain for a constant exercise protocol over the course of pregnancy.
B) To determine the relationship between physiological (heart rate, tympanic temperature and mean skin temperature) and perceptual (rate of perceived exertion and thermal sensation) measures of exertional and thermal strain for a constant exercise protocol over the course of pregnancy.

Based on the current literature, it is hypothesized that:

1. Change in metabolic heat production resulting from exercise will increase over the course of pregnancy in response to a set exercise protocol.
2. A) The increase in metabolic heat production over the course of pregnancy in response to a set exercise protocol will result in higher heart rate, tympanic temperature and mean skin temperature as well as an increase in the maximal level or perceived strain (exertional and thermal).

B) Based on known concepts of exercise and thermal physiology, early in pregnancy, a positive linear correlation will be observed for heart rate versus rate of perceived exertion as well as tympanic temperature and mean skin temperature versus thermal sensation, but these relationships will be altered as pregnancy progresses.

Chapter 2: General Methodology

2.1 Objective 1: Assessment of Metabolic Heat Production

2.1.1 Participants

The present experimental protocol was approved by the Ottawa Health Science Network Research Ethics Board as a sub-study within the CIHR –funded PLACENTA trial (REB Protocol #20160178-01H, MOP- 142298) and the University of Ottawa Health Science Research Ethics Board (REB Protocol # 11-17-190). As such, the presented study was performed in accordance with the Declaration of Helsinki. Before participation in the study, informed and written consent was obtained on a voluntary basis from all participants.

All pregnant participants were selected from those who identified interest in participating in the Physical Activity and dietary implications Throughout pregnancy (PLACENTA) study. Participants were recruited from regional Ottawa hospitals, midwifery centres as well as university campuses and social media platforms.

Eleven healthy pregnant and eleven non-pregnant women (CON) of childbearing age participated in objective one designed to examine the change in metabolic heat production across pregnancy. Of the pregnant women, one was excluded as she was unable to complete the exercise protocol due to hip pain. Additionally, due to technical error, the data of one CON participant was not usable. As a result, a total of ten pregnant and ten CON participants were included in the analysis of the data. Participant characteristics of objective one are presented in Table 1.

All pregnant women recruited for the present study were between 18- 40 years of age, less than 28 weeks pregnant, carrying a single fetus. The women were weight stable at least six months before pregnancy (\pm 2kg/5lbs) with a pre-gravid BMI between 18.5 and 29.9 kg/m². CON

participants were selected and matched based on age and pre-pregnancy weight and BMI to that of the group average for the pregnant participant.

Participants were excluded if they met any of the following criteria: Smoking, (pre-pregnancy) insulin-treated diabetes, untreated thyroid disease, hypertension requiring medication, or contraindications to exercise (*PARmed-X for PREGNANCY: Physical Activity Readiness Medical Examination*, n.d.).

2.1.2 Experimental Protocol

Upon successful completion of the recruitment and pre-screening, pregnant participants were invited to visit the *Prevention in the Early Years* laboratory located at Lees campus of the University of Ottawa two or three times. The first visit took place during the first trimester (T1); between weeks 12 and 16. The second visit took place during the second trimester (T2): between weeks 24 and 28 and a third trimester (T3) visit between weeks 34 and 38 of gestation. CON participants were asked to visit the lab for only one testing session.

Participants were asked to arrive to each visit fasted (minimum 8 h) at which time they were given a small snack to eat. The snack consisted of a piece of fruit (choice between an apple or orange), juice (choice between orange juice or cranberry) and a granola bar (choice between Kashi – Seven Grain with Quinoa, Chocolate Chip Chia or Nature Valley – Roasted Nut Crunch). While all snack options were similar in caloric (approximately 370 kcal) and nutritional content, providing an element of control for all pre-test meals, there may have been inconsistency in snack choice between visits due to the nature of appetite sensitivity throughout pregnancy.

Upon finishing their snacks, participants were asked to change into exercise clothing. Researchers then measured participant height and weight using a stadiometer (Tanita, HR-200) and a digital weighing scale (Sartorius, Combics 2, precise to 1g) respectively. Participants were

then instrumented with a HR monitor belt worn around the chest before entering the thermal chamber (CANTROL, Environmental Systems Ltd.) regulated at 23.1 ± 0.2 °C. Once inside, participants were fitted with a mask (full description stated below under Measurements) and were asked to sit and relax on a reclining chair for 20 min to assess resting energy expenditure. During this time, participants were isolated from researchers and any outside noise and movement to ensure a resting HR could be achieved when measuring baseline energy expenditure. Following the resting period, participants were then guided to a treadmill where they were instructed on the exercise protocol. The graded exercise protocol used was a variation of the HALO Submaximal treadmill protocol (Appendix A), consisting of a 4 min warm up at a walking speed of 2 mph and 0% incline. Directly following the warm-up, the seven stages of the test began wherein at the beginning of each stage the treadmill incline increased 2% for a maximum of 14% by stage seven. Each stage of the test was 3 min in duration. Throughout the test, participant respiration and HR were monitored.

2.1.3 Measurements

HEAT PRODUCTION

Expired gases were pulled through a T-type, one-way, non-rebreathing valve (Series 2700 Large; Hans-Rudolph, Shawnee, KS) using a mass flow generator/controller (FK500, Sable Systems International Inc, Las Vegas, NV USA) set at 100L/min, at standard temperature, pressure and dry (STPD) conditions during rest and at 200L/min during exercise. Inspired and expired O₂, CO₂ and H₂O concentrations were measured from a 250 ml/min subsample using a field metabolic system (FMS; Sable Systems International Inc. Las Vegas, NV USA). Rate of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were calculated using the following equations:

$$\dot{V}O_2 \left(\frac{L}{min} \right) = Flow\ Rate \left(\frac{L}{min} \right), STPD \times (fiO_2 - feO_2)$$

$$\dot{V}CO_2 \left(\frac{L}{min} \right) = Flow\ Rate \left(\frac{L}{min} \right), STPD \times (feCO_2 - fiCO_2)$$

where fiO_2 and $fiCO_2$ are the fractions of the measured gas in the ambient air; and feO_2 and $feCO_2$ are the fractions of the measured gas leaving the mouthpiece. Gases were corrected for P_{H_2O} . Measurements were taken continuously throughout the protocol. H_{prod} was calculated as the difference between metabolic energy expenditure and the external work output.

$$H_{prod} = Metabolic\ Rate - Work\ Output$$

Metabolic rate (\dot{M}), was calculated from the respiratory exchange ratio ($RER = \dot{V}CO_2 / \dot{V}O_2$) through the following equation:

$$\dot{M} (kJ/min) = \left[\dot{V}O_2 \left(\frac{L}{min} \right) \cdot \left(\frac{RER - 0.7}{0.3} e_c + \frac{1 - RER}{0.3} e_f \right) \right]$$

Where VO_2 and VCO_2 were used under STPD conditions. The caloric equivalent per litre of the oxygen of carbohydrates, e_c (21.13 kJ per L of O_2 consumed) and of fat, e_f (19.63 kJ per L of O_2 consumed) was used in the calculations.

External work was calculated over the course of the treadmill walking protocol based on participant's body mass (kg) and vertical distance travelled (m) on a calibrated treadmill:

$$Work (kJ/min) = Body\ Mass (kg) \cdot Speed \left(\frac{m}{min} \right) \cdot \sin(\theta) \cdot 0.0098 \frac{kJ}{kg \cdot m}$$

Where $1\ kg \cdot m = 0.0098\ kJ$.

2.1.4 Statistical Analysis

All statistical analyses were completed using the SPSS Statistics software (Version 24.0 for Windows; IBM, Armonk, NY). Descriptive statistics were performed for participant

characteristics including age (years), height (cm), pre-pregnancy BMI (kg/m^2), as well as pre- and post-trial body weight changes (to account for possible sweat loss).

All values were reported as means \pm standard error (SE) unless otherwise stated. When a main effect was observed, *post hoc* analysis was performed using two-tailed Student's paired or independent samples t-tests. For all analyses, the level of significance was set at $p \leq 0.05$.

REE was compared between CON and pregnancy conditions using t-tests for two independent samples, while comparisons of responses in the first, second and third trimester of pregnancy (T1, T2, and T3, respectively) were analysed through one-way analysis of variance (ANOVA) with repeated measures. $\dot{V}\text{O}_2$ values were plotted as a function of stage of exercise in CON and pregnant participants and responses at the final stage of exercise were compared between the gestational conditions. Subsequently total H_{prod} was plotted as a function of stage of exercise from which area under the curve (AUC) was calculated in CON and pregnant participants. Absolute and relative H_{prod} responses of CON participants were compared to that of the pregnant group at each trimester using t-tests for two independent samples. In the pregnant population, absolute and relative H_{prod} values were analysed using a within-subject design comparing T1, T2, and T3, through a repeated measure ANOVA. Where appropriate, all p-values were adjusting for multiple comparisons using the Bonferroni correction.

Table 1. Participant characteristics for non-pregnant control (CON) and pregnant women at trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3).

	CON	T1	T2	T3
N	10	10	10	10
Age (yrs)	30 ± 1	32 ± 1	-	-
Weight (kg)	60.2 ± 7.0	65.7 ± 3.1	71.6 ± 3.2	77.1 ± 3.8
BMI (kg/m ²) *	22.3 ± 2.0	22.8 ± 0.9	-	-
Gestation (wks)	-	15.4 ± 0.9	26.4 ± 1.1	35.3 ± 1.1

Values presented as means ± SE.

*Self-reported pre-gravid BMI was used for the pregnant participants.

2.2 Objective 2: Assessment of Physiological and Perceptual Measures of Heat Strain

2.2.1 Participants

Please refer to section 2.1 for details on ethical approval, and participant inclusion and exclusion criteria.

Given the significant differences in H_{prod} observed between the different stages of pregnancy (please refer to Chapter 3 for results), the thesis sought to examine how the increase in H_{prod} influenced physiological and perceptual measures of exertion and heat strain. Based on the findings of the first objective indicating the similarity in responses between CON and T1, in the second objective (A and B), CON participants were used as an indicator for both pre-pregnancy and a surrogate for early pregnancy responses. As a result, for this section of the study, pregnant women were only asked to visit the lab at T2 and T3.

Twenty-three healthy pregnant and sixteen CON women of childbearing age were recruited to participate in this portion of the study. Of the pregnant participants, one was excluded due to medical directive to refrain from exercise, and two were excluded from the study as they were unable to finish the exercise protocol due to hip pain and syncope. In total, twenty pregnant and sixteen CON participants completed the exercise protocol. Participant characteristics for subjects in objective two are presented in Table 2.

2.2.2 Experimental Protocol

Participants underwent the same experimental protocol outlined in section 2.2 with the following additions:

Participants were instrumented with four skin temperature sensors situated on the right side of the body at the following sites: chest, biceps, quadriceps, and calf to allow for a measure of

mean skin temperature (\bar{T}_{skin}). Each sensor was secured in place with medical tape. Once in the thermal chamber, participants were also instrumented with a tympanic thermocouple to allow for continued monitoring of changes in tympanic temperature (T_{tymp} , as a surrogate for T_{core}) through a hand-held data acquisition system (OMEGA. DaqPRO-5300, OMEGA Engineering). Finally, at the end of each stage during the test, participants were asked to rate their perceived exertion and TS on the BORG RPE scale and TS scale (Zhang, Arens, Huizenga, & Han, 2010), respectively. Following the completion of the protocol, participants were then de-instrumented which concluded the testing.

2.2.3 Measurements

HEART RATE AND THERMAL RESPONSES

HR was continuously measured throughout the protocol using a HR monitor (Polar V800, Polar Electro Canada) with a one-second epoch. Measurements were presented as an average of the last 30 seconds of each stage of the exercise protocol. T_{tymp} was monitored via a tympanic thermistor (F/400 series, CardinalHealth) throughout the protocol and recorded using a one-second epoch and were presented as an average of the last 30 seconds of each stage of the exercise protocol. T_{skin} was measured using autonomous wireless temperature sensors (Thermochron iButton model DS1922H, Maxim) at four skin sites: chest, bicep, thigh and calf. \bar{T}_{skin} was calculated based on the following weighted proportions: 30% chest, 30% bicep, 20% thigh, 20% calf (Ramanathan, 1964) .

RATE OF PERCEIVED EXERTION AND THERMAL SENSATION

RPE was assessed at the end of each stage of exercise using the 14-point scale (Appendix B). RPE responses were considered both for estimation of participant comfort and for a measure of perception of physical exertion. TS was assessed at the end of each stage of the rest and exercise protocol using the 9-point scale (Zhang et al., 2010)(appendix C).

2.2.4 Statistical Analysis

For full details on method and presentation of statistical analysis including software used, please refer to section 2.4. A comparison of resting HR, T_{tymp} and \bar{T}_{skin} values were performed between pregnant and CON using student's t -tests for two independent samples while differences between T2 and T3 were assessed with paired sample t -tests. Similarly, changes in physiological strain in response to exercise (i.e. the difference in HR, T_{tymp} and \bar{T}_{skin} from the end of stage 1 to stage 7) between CON and pregnancy were compared using Student's t -tests for two independent samples while differences between T2 and T3 were assessed with paired sample t -tests. Given the Likert nature of the BORG and TS scale, maximal perceived strain (i.e. RPE and TS measures at the end of stage 7 of exercise) was compared between CON and the two pregnancy time points, T2 and T3, using the Mann Whitney U test for non-parametric, ordinal data. The Wilcoxon Sign-Rank Test was conducted to assess differences between T2 and T3.

Kendall ranked correlation (Kendall's Tau, T) was used to assess the relationship between RPE and the corresponding HR values at each gestational condition (CON, T2, and T3). Similarly, Kendall ranked correlation was performed between TS and T_{tymp} as well as TS and \bar{T}_{skin} at each gestational condition. Physiological responses were assessed as continuous variables while perceptual data were assessed as ordinal variables.

Correlations were compared between CON, T2 and T3 descriptively.

Table 2. Participant characteristics for non-pregnant control (CON), and pregnant women at trimester 2 (T2) and trimester 3 (T3).

	CON	T2	T3
N	16	20	20
Age (yrs)	32 ± 1	32 ± 1	-
Weight (kg)	62.1 ± 2.2	71.1 ± 2.0	75.1 ± 2.0
BMI (kg/m ²)*	22.7 ± 1.1	23.2 ± 0.6	-
Gestation (wks)	-	26.0 ± 1.0	35.5 ± 1.0

Values presented as means ± SE.

*Self-reported pre-gravid BMI was used for the pregnant participants.

Chapter 3: Results

3.1 Objective 1: Metabolic Heat Production

3.1.1 Participant Characteristics

Of the participants who completed the protocol, age and BMI (pre-pregnancy for pregnant) were similar between the CON (30 ± 1 yrs, 22.3 ± 2.0 kg/m²) and pregnant subjects (32 ± 1 yrs, 22.8 ± 0.9 kg/m²) (both $p \geq 0.18$). On average, all pregnant women in the study experienced GWG within the guidelines set forth by the IOM (Gilmore et al., 2016). Body weight was not different between CON and T1 ($60.2 \pm 3.1.0$ kg and 65.7 ± 3.1 kg respectively, $p = 0.22$) however, higher in T2 and T3 (71.6 ± 3.2 kg and 77.1 ± 3.8 kg respectively, both $p \leq 0.01$) relative to CON. Furthermore, body weight increased in each trimester of pregnancy (all $p < 0.01$).

3.1.2 Heat production

Baseline REE in the four pregnancy conditions are presented in Figure 2. While no differences were observed in REE between CON and T1 (5.3 ± 0.4 kJ/min and 6.2 ± 0.3 kJ/min, respectively; $p = 0.64$), REE steadily increased as pregnancy progressed such that T2 (6.8 ± 0.3 kJ/min) and T3 (7.2 ± 0.4 kJ/min) were significantly higher than CON (both $p \leq 0.01$). Moreover, in comparison to T1, REE in T2 and T3 were also significantly higher (both $p \leq 0.02$) however, baseline REE did not differ between T2 and T3 ($p = 0.26$).

$\dot{V}O_2$ at baseline rest and at each stage of exercise are presented in Figure 3. Relative to CON (1.4 ± 0.1 L/min), $\dot{V}O_2$ responses at the final stage of exercise were higher in T1, T2 and T3 (1.7 ± 0.1 L/min, 1.8 ± 0.1 L/min, and 2.0 ± 0.1 L/min, respectively; all $p \leq 0.026$). Moreover, $\dot{V}O_2$ were significantly different between all three trimesters of pregnancy (all $p \leq 0.005$).

After considering the differences in REE in each gestational condition, work output at each stage (Figure 4) was used to calculate exercise induced change in H_{prod} (illustrated in Figure 5). Relative to CON, H_{prod} in T1 was similar at all stages of exercise (all $p \geq 0.06$) except stage 5 and 6 ($P = 0.04$ and 0.05 , respectively). Conversely, H_{prod} in T2 and T3 were higher than CON at all stages (all $p \leq 0.03$), except stage 1, where-in responses between CON and T2 were not significantly different ($P = 0.06$). Relative to T1, H_{prod} in T2 was higher at stages 4 and 5 (both $p \leq 0.05$) while responses in T3 were significantly higher at every stage of the exercise (all $p \leq 0.02$) with the exception of stage 2 ($p = 0.06$). In the last three stages of exercise, responses between T2 and T3 were also significantly different such that change in H_{prod} was higher in T3.

A comparison of absolute H_{prod} calculated as area under the curve resulting from completion of the entire exercise protocol at each time point in gestational is presented in Figure 6. The findings indicate no difference in the absolute H_{prod} between CON and T1 (308.3 ± 15.4 and 352.3 ± 18.8 kJ/min, respectively, $p = 0.06$), while relative to CON, responses in T2 (379.8 ± 22.0 kJ/min) and T3 (412.9 ± 24.7 kJ/min) were elevated (both $p \leq 0.02$). In parallel, over the course of the exercise test absolute H_{prod} in T2 and T3 were also elevated (both $p \leq 0.04$) in comparison to T1. The results indicated that in T3, H_{prod} resulting from the exercise protocol was significantly higher than that of T2 ($p = 0.03$). Assessment of relative H_{prod} , calculated as absolute H_{prod} divided by weight, resulting from the exercise protocol indicated no differences between CON and pregnancy conditions (all $p \geq 0.30$) as well as within pregnancy conditions (all $p \geq 0.64$, Figure 7).

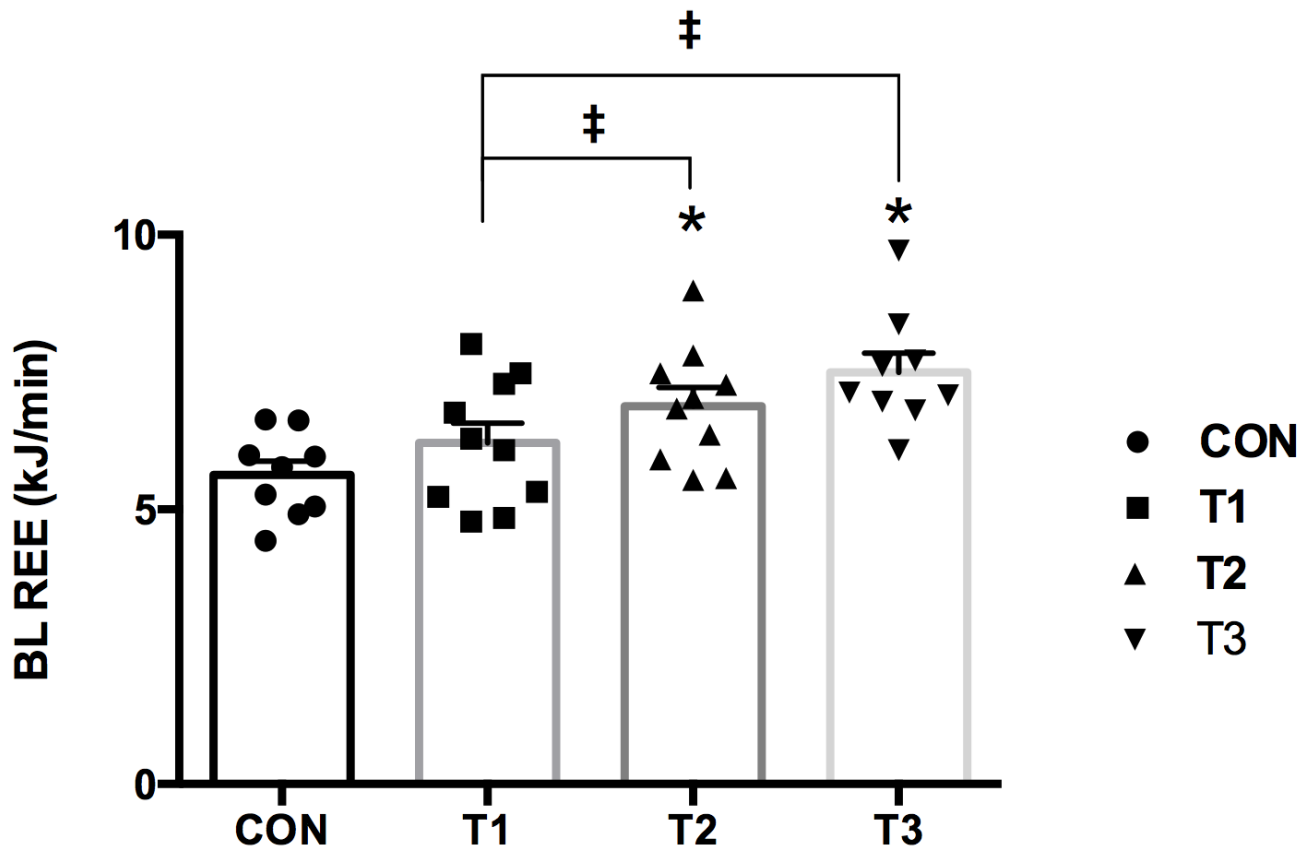


Figure 2. Baseline (BL) resting energy expenditure (REE) for control (CON), trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3). Values are presented as mean \pm SE. * Represents a difference from CON, ‡ represents a difference between T1, T2 and T3.

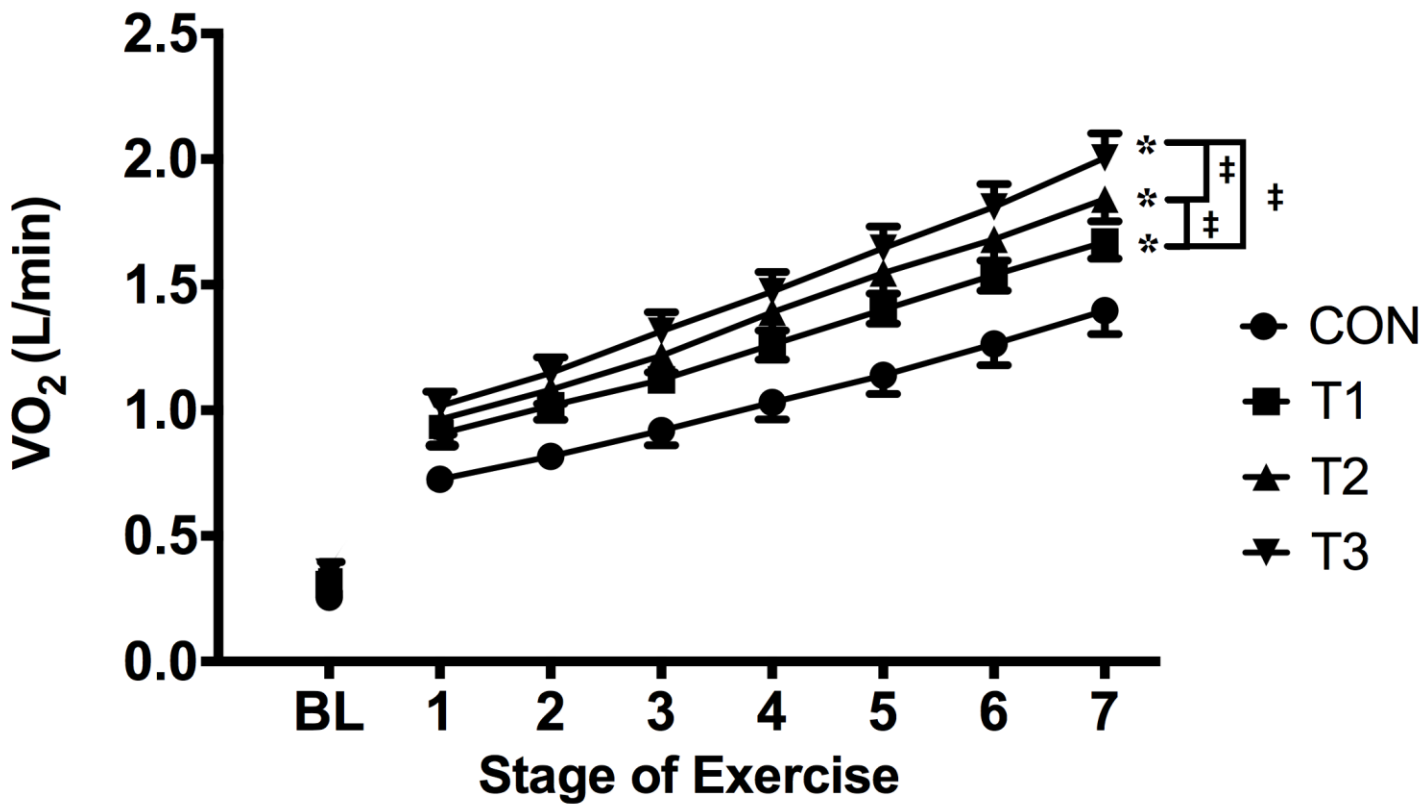


Figure 3. Rate of oxygen consumption (VO_2) at each stage of exercise for control (CON), trimester 1 (T1), trimester 2 (T2) and trimester 3 (T3). * Represents a difference from CON, ‡ represents a difference between T1, T2 and T3.

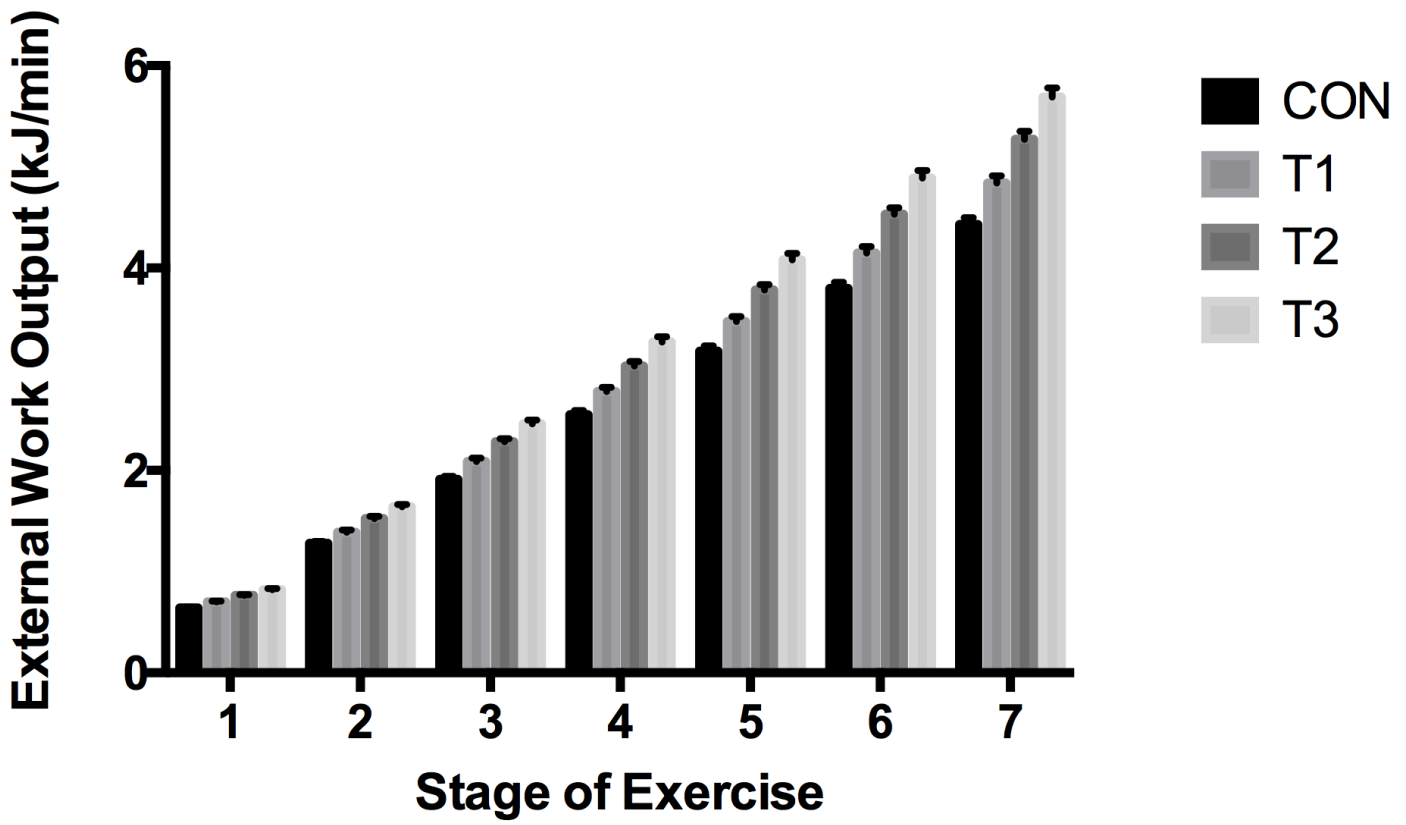


Figure 4. External work output at each stage of exercise for control (CON), trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3). Values are presented as mean \pm SE.

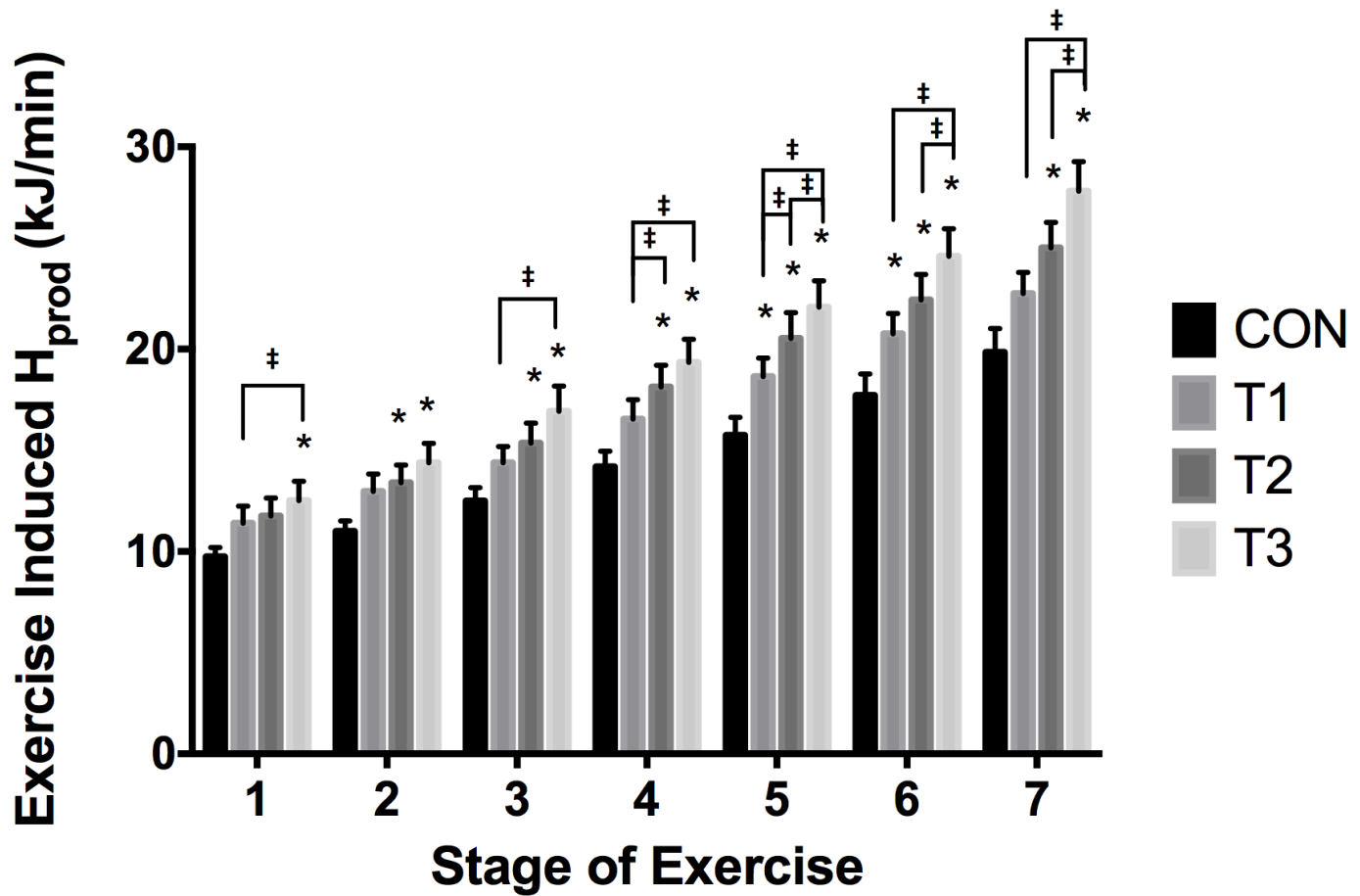


Figure 5. Change in metabolic heat production (H_{prod}) resulting from exercise at each stage of exercise for control (CON), trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3). Values are presented as mean \pm SE. * Represents a difference from CON, ‡ represents a difference between stages of pregnancy.

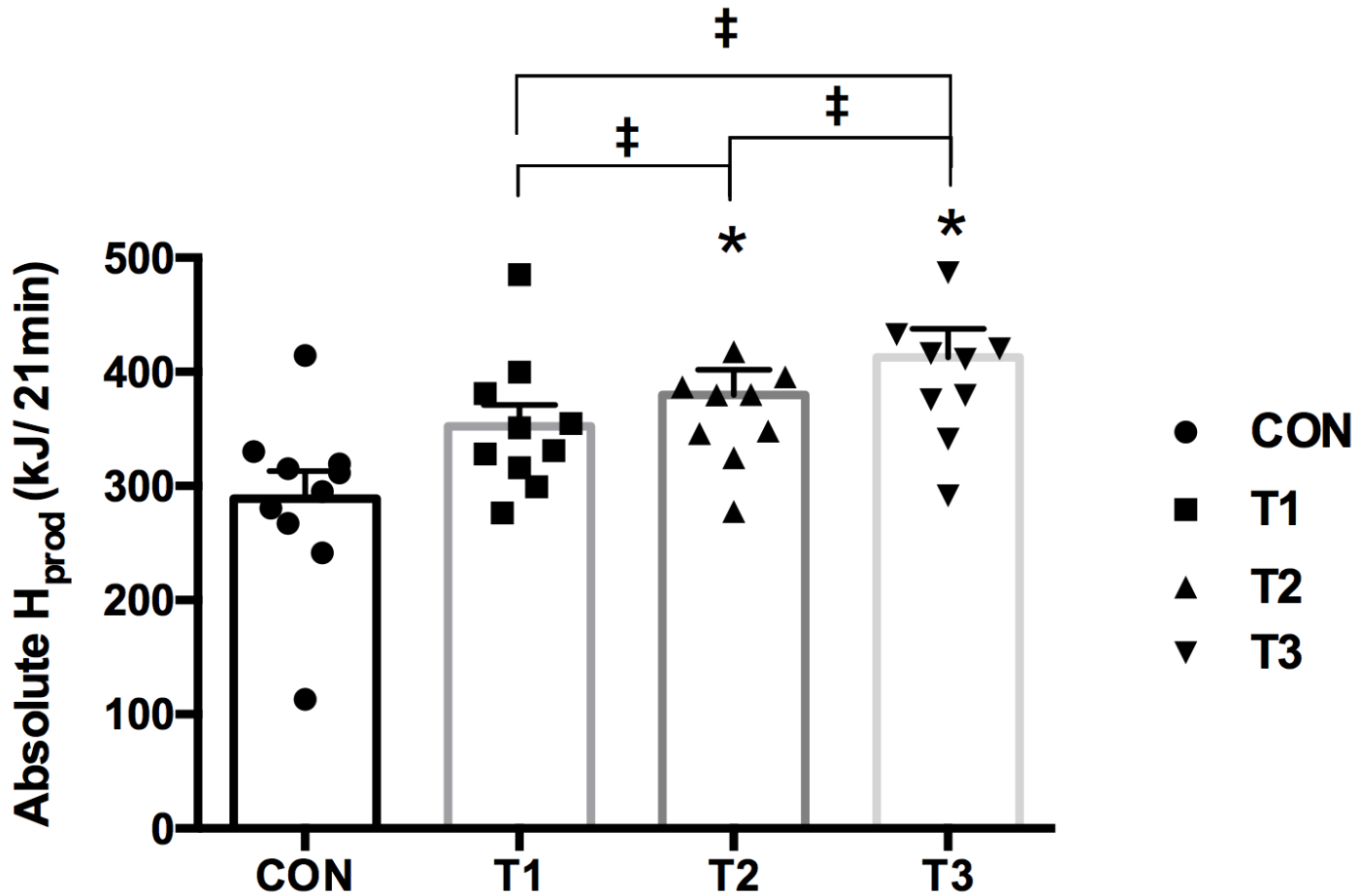


Figure 6. Absolute changes in metabolic heat production (H_{prod}) over the course of a graded exercise protocol for non-pregnant control (CON) and pregnant women at trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3). Values are presented as mean \pm SE. * Represents a difference from CON, ‡ represents a difference between stages of pregnancy.

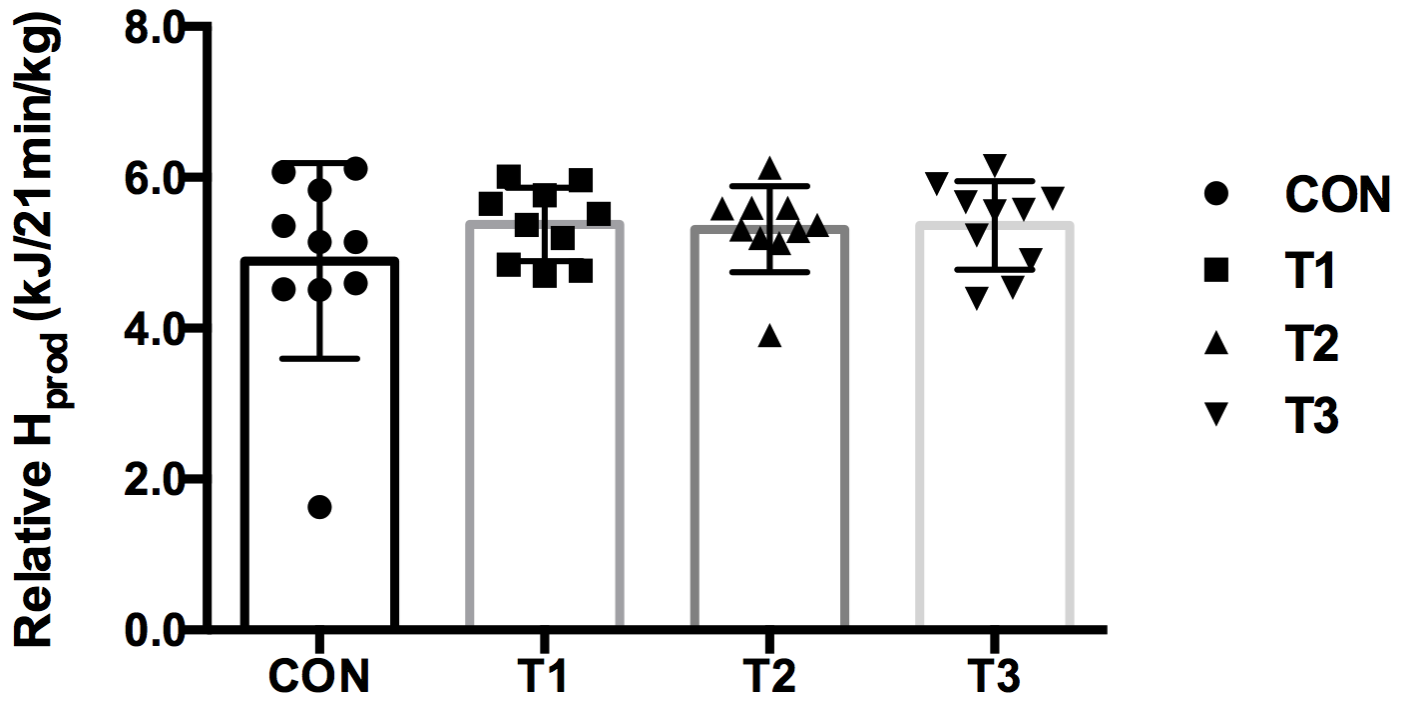


Figure 7. Relative changes metabolic heat production (H_{prod}) over the course of a graded exercise protocol for non-pregnant control (CON) and pregnant women at trimester 1 (T1), trimester 2 (T2), and trimester 3 (T3). Values are presented as mean \pm SE.

3.2 Objective 2: Physiological and Perceptual Measures of Heat Strain

3.2.1 Participant Characteristics

Of those who completed the experimental protocol, participants in the CON and pregnant group were similar in age (both 32 ± 1 yrs, $p = 0.80$), and BMI (22.7 ± 1.1 and 23.2 ± 0.6 respectively, $p = 0.60$). Relative to CON (61.3 ± 2.2 kg), body weight was higher in T2 and T3 (71.1 ± 2.0 kg and 75.05 ± 2.0 kg respectively, both $p < 0.01$). Furthermore, the body weight of participants in T3 were higher than that of T2 ($p < 0.01$).

3.2.2 Physiological Measures of Heat Strain

As depicted in Figure 8A, at baseline rest, HR response of CON (69 ± 3 bpm) was lower than both T2 and T3 (78 ± 2 and 85 ± 3 bpm, respectively; both $p \leq 0.01$). Further, HR in T2 was lower than that of T3 at baseline rest ($p = 0.03$). In response to exercise, HR increased at all stages of gestation (all $p < 0.001$), however relative to CON (34 ± 2 bpm), the change in HR between stage 1 and stage 7 was 13 bpm higher in T2 ($p = 0.02$), and 6 bpm higher in T3 ($p = 0.01$). The change in HR responses were similar between T2 and T3 ($p = 0.14$).

At baseline rest, T_{tymp} was similar between all three gestational conditions (CON: $35.8 \pm 0.2^\circ\text{C}$, T2: $35.6 \pm 0.2^\circ\text{C}$ and T3: $35.6 \pm 0.1^\circ\text{C}$, all $p \geq 0.12$) as illustrated in Figure 8B. T_{tymp} increased in all stages of gestation in response to the exercise, as measured by change from stage 1 to end of the stages 7 (all $p < 0.001$), albeit no differences were observed between the changes in CON, T2 and T3 ($0.26 \pm 0.1^\circ\text{C}$, $0.3 \pm 0.1^\circ\text{C}$ and $0.4 \pm 0.1^\circ\text{C}$, respectively; all $p \geq 0.26$).

As illustrated in Figure 8C, during baseline, \bar{T}_{skin} was higher in CON ($31.5 \pm 0.1^\circ\text{C}$) relative to T2 and T3 ($30.4 \pm 0.2^\circ\text{C}$ and $30.9 \pm 0.2^\circ\text{C}$, both $p \leq 0.03$), but significantly lower in T2 in comparison to T3 ($p = 0.05$). In response to exercise, \bar{T}_{skin} did not change in CON and T2 ($p = 0.38$ and 0.28 , respectively), but dropped by 0.18°C in T3 ($p = 0.01$, not visualized in Figure 8).

Moreover, analysis between stages of gestation showed no differences in the magnitude of change in \bar{T}_{skin} in response to exercise (all $p \geq 0.06$).

3.2.3 Perceptual Measures of Heat Strain

In comparison to CON (13 ± 0.4), RPE responses to the BORG scale at the end of stage 7 of the exercise protocol was higher in T2 (15 ± 0.3 , $U = 67.00$, $p < 0.01$) and T3 (15 ± 0.4 , $U = 55.50$, $p < 0.01$) (Figure 9A). Significant differences were observed in the RPE between T2 and T3 ($Z = -2.14$, $p = 0.03$). Furthermore, as depicted in Figure 9B, responses to the TS scale at the end of stage 7 were similar between CON and T2 (1 ± 0.3 and 2 ± 0.2 , respectively; $U = 113.00$, $p = 0.12$), but higher in T3 (3 ± 0.2) relative to CON ($U = 78.00$, $p < 0.01$) and T2 ($Z = -2.67$, $p < 0.01$).

3.2.4 Interactions between Physiological and Perceived Measures

Assessment of Kendall's ranked correlation exhibited a strong correlation between RPE and HR responses in the CON ($\tau_b = 0.98$, $p < 0.01$) as well as in T2 and T3 (both $\tau_b = 1.00$, both $p < 0.01$) (Figure 10). In the assessment of the relationship between TS and the physiological measures of T_{tymp} and \bar{T}_{skin} (Figure 11, panel A and B respectively), correlation results were varied. In relation to T_{tymp} (Figure 11A), a moderate relationship was observed with TS in CON ($\tau_b = 0.76$, $p = 0.02$). Moreover, there was a strong correlation between the TS and T_{tymp} in T2 ($\tau_b = 0.91$, $p < 0.01$) and T3 ($\tau_b = 1.00$, $p < 0.01$). Correlation analysis run using Kendall's Tau between the variables of TS and \bar{T}_{skin} in CON exhibited no correlation ($\tau_b = -0.05$, $p = 0.89$) (Figure 11B). Similarly, a weak correlation was observed in these variables in T2 ($\tau_b = 0.20$, $p = 0.52$). In contrast, in T3, a strong negative correlation was observed between TS and \bar{T}_{skin} ($\tau_b = -0.93$, $p < 0.01$) such that at the highest perceived level of TS, participants experienced the lowest \bar{T}_{skin} .

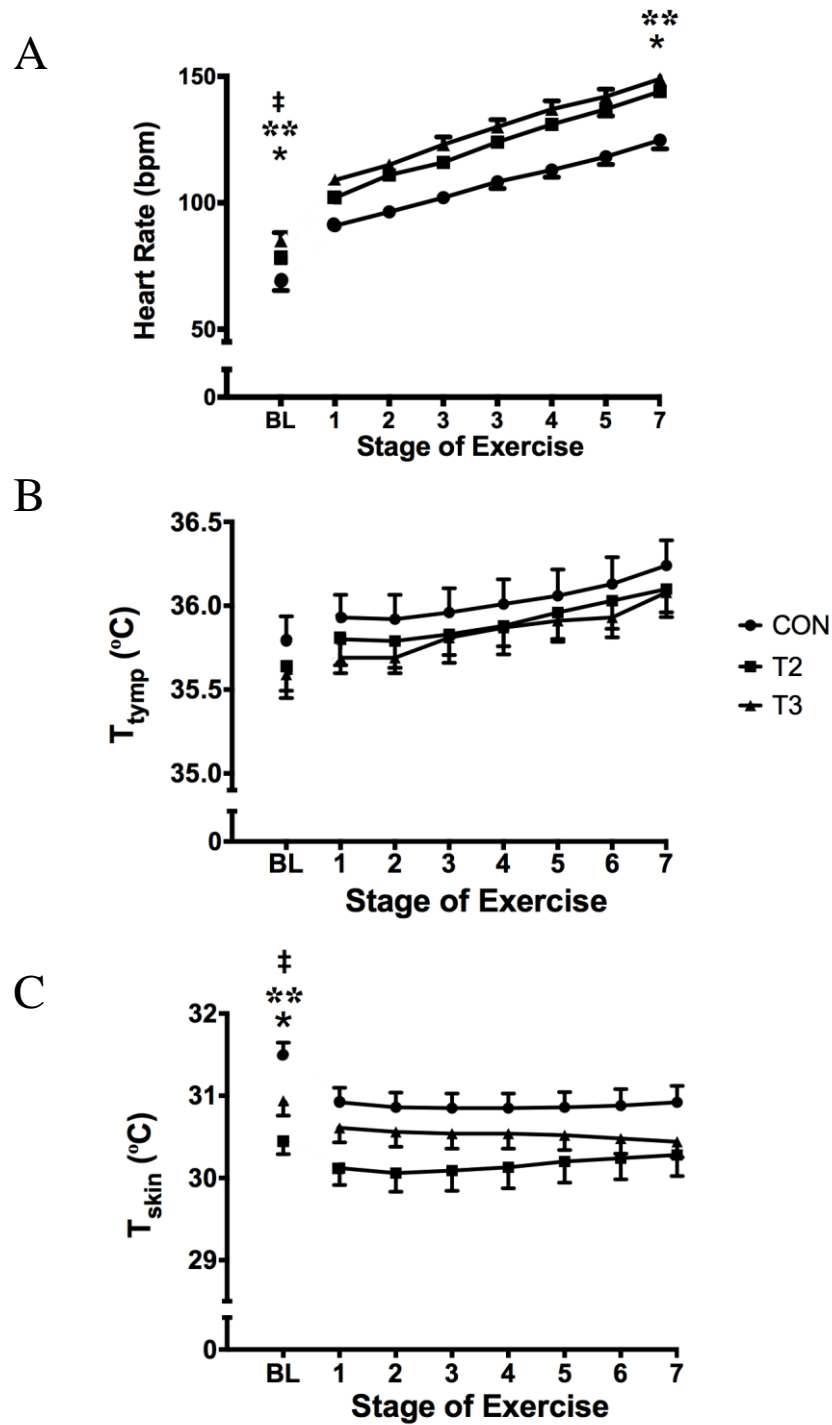


Figure 8. Changes in heart rate (A), tympanic temperature (T_{tymp} , B) and mean skin temperature (T_{skin} , C) were assessed for control (CON), trimester 2 (T2), and trimester 3 (T3) at baseline rest (BL) and throughout seven stages of exercise. Values are presented as mean \pm SE. * Represents significant difference between CON and T2, ** represents significant difference between CON and T3, and ‡ represents significant difference between T2 and T3.

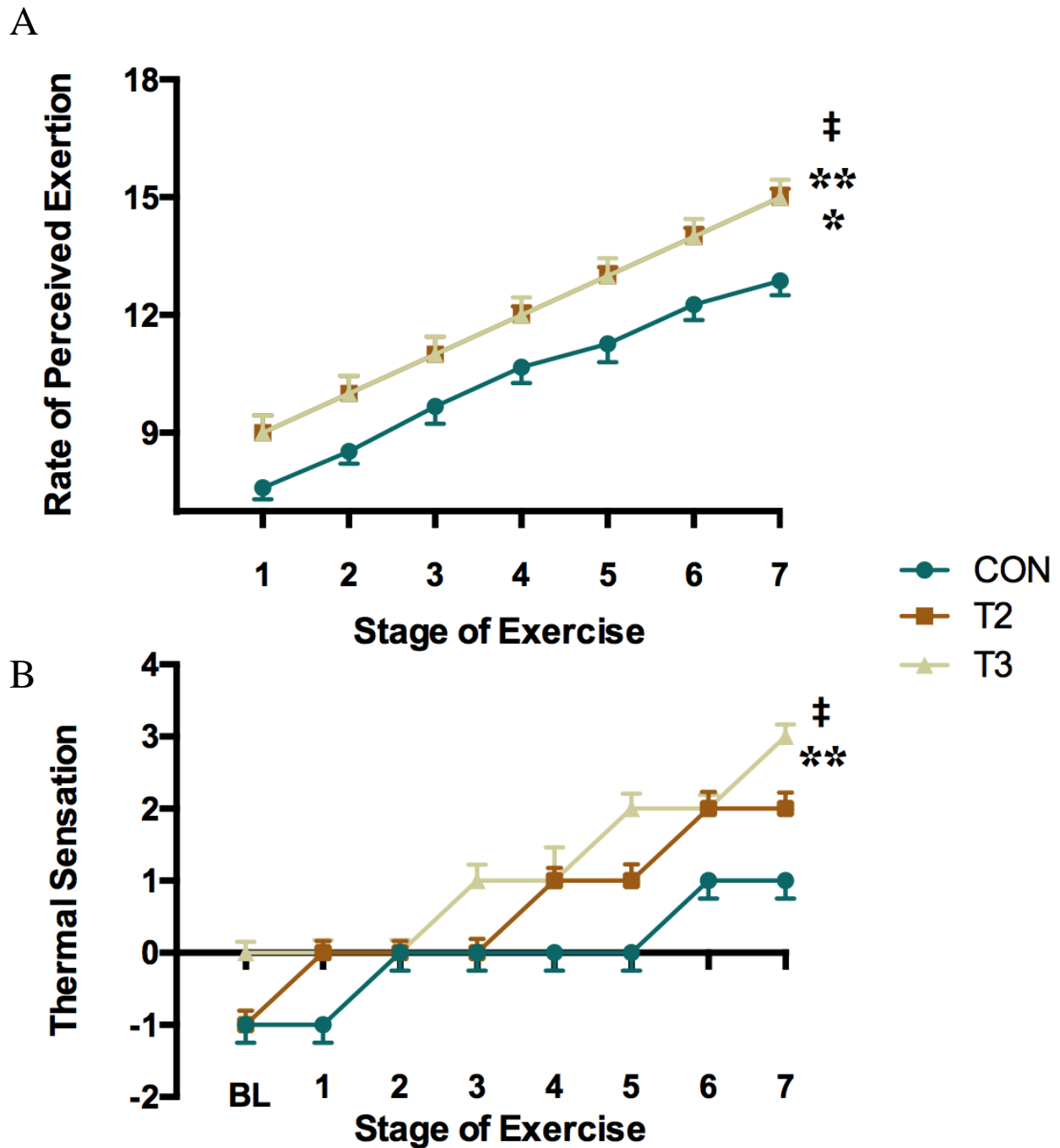


Figure 9. Perceptual responses to the exercise protocol. Responses of rate of perceived exertion (A) and thermal sensation (B) are presented for control (CON), trimester 2 (T2), and trimester 3 (T3) at baseline rest (BL, in thermal measures) and throughout seven stages of exercise. Values are presented as mean \pm SE. * Represents a significant difference between CON and T2, ** represents a significant difference between CON and T3, and ‡ represents a significant difference between T2 and T3.

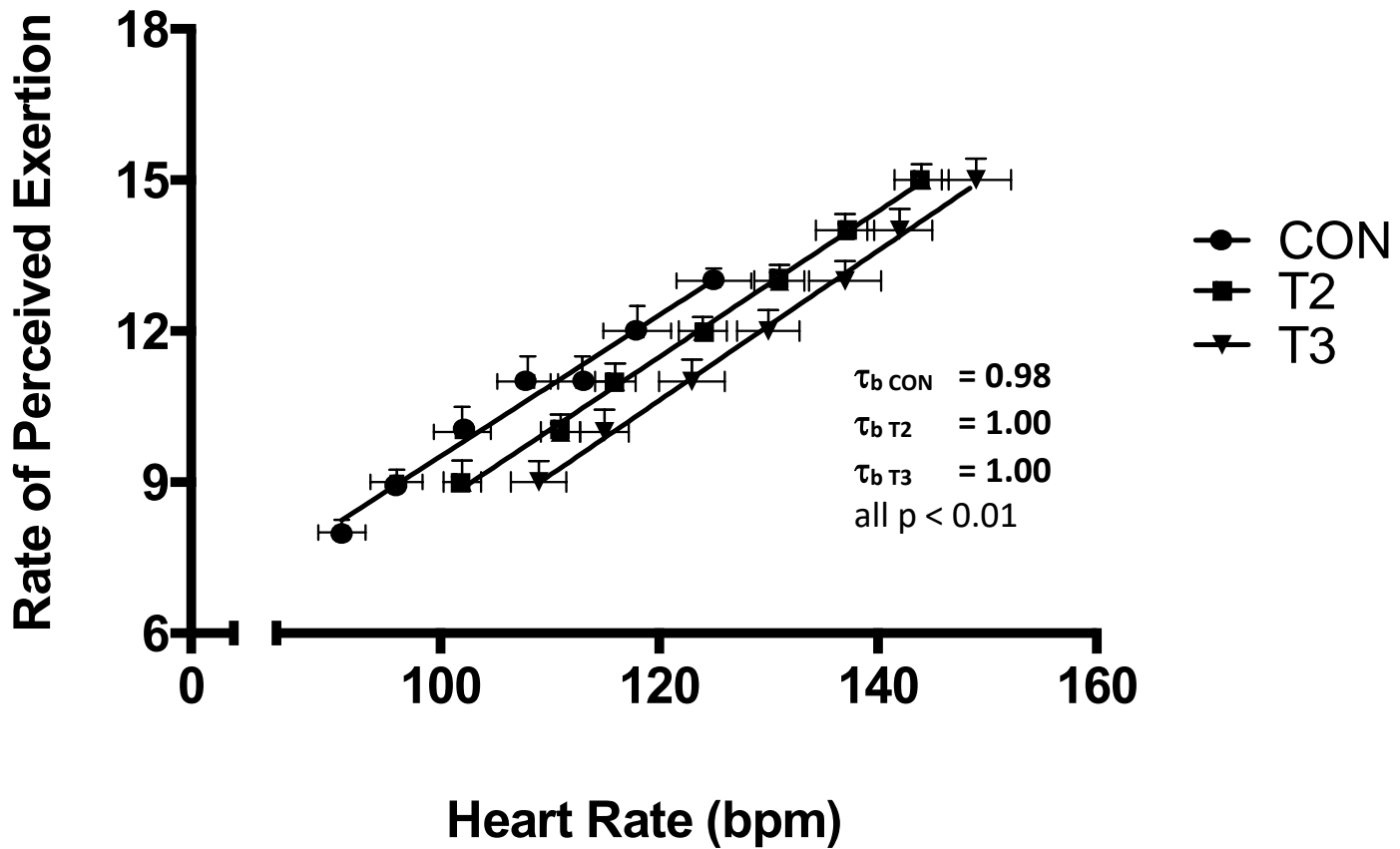


Figure 10. Group correlation between rate of perceived exertion and heart rate for control (CON), trimester 2 (T2), and trimester 3 (T3) throughout the seven stages of exercise. Values are presented as group mean \pm SE such that horizontal error bars represent SE heart rate while vertical error bars represent SE of rate of perceived exertion.

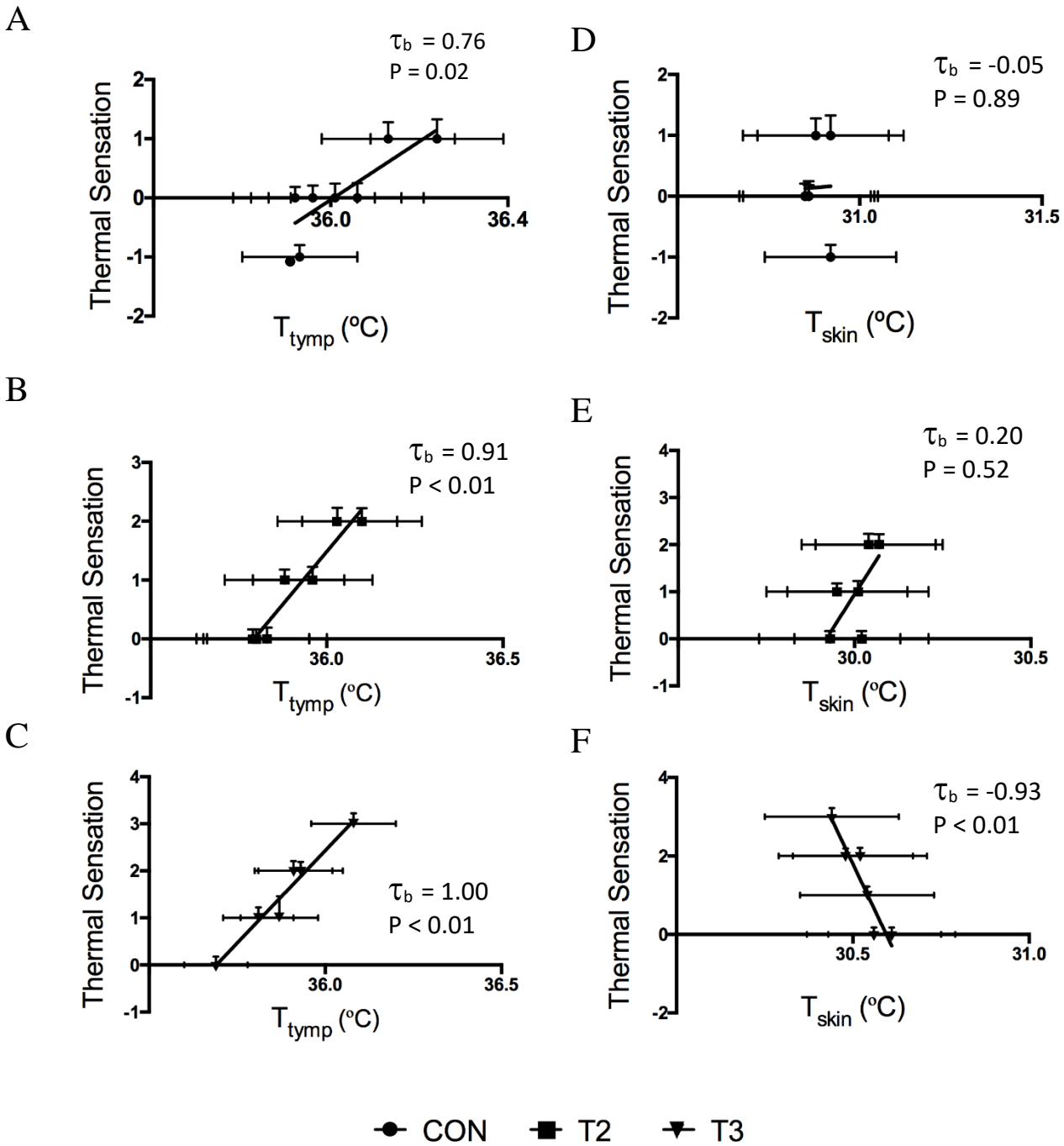


Figure 11. Group correlation between thermal sensation and physiological responses of tympanic temperature (T_{tymp}) and mean skin temperature (\bar{T}_{skin}). Group correlations for thermal sensation between T_{tymp} (A, B, C) and T_{skin} (D, E, F) are presented for CON, T2 and T3 throughout the seven stages of exercise. Values are presented as group mean \pm SE such that horizontal error bars represent SE of T_{tymp} (A) and T_{skin} (B), while vertical error bars represent SE of thermal sensation.

Chapter 4: Discussion

Due to concerns for fetal wellbeing, the impact of physical exertion during pregnancy has long been a contested issue. In more recent years, exercise has not only been deemed safe, but encouraged by health care providers as a means of increasing quality of life and reducing adverse antenatal outcomes (Committee on Obstetric Practice, 2002; Davies et al., 2003; Hesketh & Evenson, 2016). While the promotion of PA is now widespread, there is still an absence of research examining and quantifying the influence of pregnancy on heat production: a basis for which heat stress can arise. This thesis aimed to quantify changes in H_{prod} over gestation and evaluate how physiological and perceptual strains are altered in response to the changes in H_{prod} resulting from a set exercise throughout pregnancy. The experimental results show a progressive increase in H_{prod} from early to late pregnancy accompanied with changes in physiological and perceived measures of heat strain that suggest improved thermoregulation during pregnancy. The present findings develop the understanding of the interplay between physiological and perceptual cues in the pregnant population; information that can aid in the understanding of exercise behaviours throughout gestation.

4.1 Increase in Heat Production throughout Pregnancy

Using indirect calorimetry, baseline resting respiratory responses demonstrated that women's REE increases with gestation. This finding, in line with previous research (Bronstein, Mak, & King, 1996; Butte, Wong, Treuth, Ellis, & Smith, 2004; Lof et al., 2005; Prentice & Goldberg, 2000), was expected given the anticipated GWG that has been shown to account for up to 40% of changes in basal metabolic rate (Bronstein et al., 1996; Lof et al., 2005). It is acknowledged, however, that in the present study accurate methods of measuring REE were not employed given that participants were provided a snack (i.e. not fasted) before for the measurements. As such, the

present 'REE' results are not appropriate for widespread comparison, but rather intended for the sole purpose of accounting for the inter-trimester metabolic variability within the calculations of H_{prod} going forward.

Quantifying the change of REE in participants allowed the removal of this factor from the subsequent measures of rate of H_{prod} during exercise. It should be highlighted that the current protocol was designed to represent the range of intensities undertaken by the modern woman in daily life and decisively held constant throughout each trimester to isolate the influence of pregnancy on H_{prod} . Ventilation rates during exercise were assessed in all participant groups and showed to increase throughout exercise (Figure 3) in response to increasing work output (Figure 4). Moreover, as pregnancy progressed, the $\dot{V}O_2$ requirement for completion of the final stage of exercise also significantly increased. Accordingly, H_{prod} increased in all stages of gestation over the exercise protocol however, of greater interest is the differences in responses between the pregnancy time points. Figure 5 highlights the similarity in responses of CON and T1 throughout the protocol. In fact, with the exception of stage 5 and 6, the responses of these two groups are not significantly different from one another. Based on this finding, there is no significant change in H_{prod} in early gestation compared to the non-pregnant state. In contrast, responses of CON are consistently lower than that of T2 and T3 at the beginning of the exercise. This trend is also noted in T1 versus T2 and T3 as exercise progresses. Further, by stage 5, even the disparity between T2 and T3 becomes significant and remains so throughout the remainder of the exercise protocol. As hypothesized, and as summarized in Figure 6, the absolute H_{prod} resulting from a set exercise protocol increases with gestation. The present findings also show a lack of difference in H_{prod} between CON and T1 suggesting that these conditions are not significantly different from one another. One major limitation of the present study was the inability to use the pregnant female

participants as their own controls. Due to time restrictions and recruitment methods available for this research, recruitment of women pre-conception was not feasible. This was compounded by the fact that nearly half of all pregnancies are unplanned (Henshaw, 1998). Furthermore, the alternative of using post-partum responses as a surrogate for pre-pregnancy control responses has been proven ineffective given the unique thermal responses during the post-partum phase (Jones et al., 1985). Thus, while ideal to utilize the same women preconception and during pregnancy I elected to match non-controls for biophysical characteristics in hopes of mitigating the differences in participant variability.

Despite the differences observed between the stages of pregnancy, it is important to gauge the implications and significance of the magnitude of the observed increases in H_{prod} . As the data presented here show, on average, for a given absolute workload, women will experience a 7-8% increase in H_{prod} with each progressing trimester. Thus, by T3, a pregnant woman undergoing the same moderate intensity activity (representative of stage 7) as her T1 self would experience a 27.5 kJ increase in H_{prod} – a quantity that is insignificant in the context of daily energy expenditure.

Given that the women's weight progressively increased over the course of pregnancy, I then sought to assess if the changes in H_{prod} could be accounted for by weight gain through assessment of relative H_{prod} . As depicted in Figure 7, when absolute H_{prod} values are divided by participant weight, the differences previously observed between stages of gestation no longer persist. Consequently, based on the data presented, the changes in H_{prod} are primarily accounted for by pregnancy-related weight gain.

Overall, these results support the notion that, while exercising at intensities representative of PA in daily life creates a greater physiological challenge as pregnancy progresses (due to increases in weight), this challenge does not seem to be one that the body cannot accommodate. In a healthy

pregnancy, engaging in moderate-intensity physical activity, as was performed in this study, is highly unlikely to pose a threat to the wellbeing of the fetus or mother.

This study is the first to quantify the changes in H_{prod} over the course of pregnancy. While the pregnant subjects were not able to be used as their own pre-pregnancy controls, the strength of the present study lies in the repeated measures methodology, which followed ten women from early through to late pregnancy. Additionally, the exercise model was designed with real life in mind such that the exercise task incorporated intensities of walking that the average women could expect to experience throughout an active week.

Unlike the present work, multiple studies examining thermoregulation in this population have used H_{prod} as a constant in their methodological design (Clapp, Wesley, & Sleamaker, 1987; Jones et al., 1985) by adjusting the workload or relative intensity of the exercise tasks over the course of pregnancy. By doing so, these studies were unable to gain a comprehensive understanding of the compounding strain of exercise and pregnancy and thus are unable to measure the thermoregulatory capacity of the female body throughout pregnancy. Given the impact that exercise-induced H_{prod} has on physiological heat strain, the quantification of changes in H_{prod} throughout pregnancy provides a basic understanding from which further exploration of thermodynamics can be examined in the pregnant population.

4.2 Physical Measures of Strain during Exercise Throughout Pregnancy

In response to the findings of objective one, showing a 7-8% increase in H_{prod} with each progressing trimester, the second objective of this thesis was then pursued. In doing so, the aim of the second objective was to initially determine the physiological and perceptual responses to the exercise and the resulting increases in H_{prod} and subsequently examine the relationship between these measures as pregnancy progressed.

As predicted, resting HR increased with the progression of pregnancy such that women at T3 exhibited resting HR values 16 bpm higher than their CON counterparts (Figure 8A). The observed differences between the population groups are in line with those outlined by San-Frutos and colleagues (San-Frutos et al., 2005) indicating that an increase in HR of 10-20 bpm throughout pregnancy can be expected as a physiological response to the reduction in vascular resistance during pregnancy. Interestingly, while women at both T2 and T3 had a change in HR that was significantly higher in comparison to CON (both $p \leq 0.02$), no such differences existed between T2 and T3 ($P = 0.14$). Based on the principle that change in HR is an indirect indicator of exercise strain and PA intensity (Tanaka, Monahan, & Seals, 2001), the present HR responses could suggest that the cardiovascular strain experienced in response to the exercise in T2 may begin to plateau after this stage of pregnancy. However, the significant differences observed between all three trimesters of pregnancy in $\dot{V}O_2$ requirement for completion of the exercise protocol (objective one) would suggest otherwise. During pregnancy, the rise in blood volume is accompanied with increased circulatory filling pressure and reduced vascular resistance (Poppas et al., 1997) driven by increased nitric oxide and estradiol bioavailability (Soma-Pillay et al., 2016). Together, these changes result in increased stroke volume and cardiac output starting as early as 5 weeks of gestation (Hall et al., 2011). However, it is understood that increases in stroke volume and cardiac output begin to plateau following the second trimester (Hall et al., 2011; San-Frutos et al., 2005) which would also suggest a further need for increases in HR in T3 to meet the work load demands of the exercise. Based on Fick's principle, an observed increase in measured $\dot{V}O_2$ accompanied with a lack of difference in HR, which is observed in the present findings, would suggest greater muscle oxygen uptake (Fick, 1855). Oxygen uptake, defined as arteriovenous oxygen difference, increases as a result of oxygen demand in active tissues such as those involved in exercise

(Blomqvist & Saltin, 1983). In response to physical training, physiological modifications such as increased vascularization (vasculogenesis) and mitochondrial production also mediate increases in arteriovenous oxygen difference. During pregnancy the increase in angiogenesis and vasculogenesis are vital to the development of the placenta and support of fetal growth (Burton, 2009; Zygmunt, Herr, Münstedt, Lang, & Liang, 2003) such that within the first trimester, oxygenation of the placenta increases 2-3 fold then remains constant at 50-60 mmHg until delivery (Huppertz, 2014). Despite the abundance of research examining placental oxygenation, there is little research examining changes in whole body angiogenesis and vasculogenesis during pregnancy. Thus, while the present findings suggest increased arteriovenous oxygen differences between T2 and T3, we are unable to ascertain, with the current measurements, what is causing the change. One possible explanation may be the greater muscle oxygen demand attributed to the need to support the increased load (resulting from weight gain) in T3 relative to T2 resulting in increased exercise intensity (Blomqvist & Saltin, 1983).

In the present study, the use of esophageal or rectal probes to measure core temperature were not possible as these measures would not have received ethical approval being deemed an unnecessary discomfort in the population group being tested. As a result, T_{tymp} was utilized as a surrogate for T_{core} with awareness of the inherent variability in using this technique (Moran et al., 2007; Shiraki, Konda, & Sagawa, 1986). Given this constraint, T_{tymp} was used in the present study primarily as a means of assessing changes in temperature response (Brinnel & Cabanac, 1989). Using this measurement technique, a drop in basal T_{tymp} between the CON and pregnant state (CON: 35.74°C, T2: 35.33°C and T3: 35.59°C, Figure 8B) was observed, however due to the variability in the responses, the differences observed were not significant. Nonetheless, the trend in reduced basal temperatures between CON and pregnancy time points is in line with results of

previous studies (Clapp, 1991; Hartgill et al., 2011; Lindqvist et al., 2003) wherein the reduction in basal T_{core} has been suggested to be proof of thermal modifications to protect the fetus against heat stress during gestation (Lindqvist et al., 2003). Alternatively, Charkoudian et al., (2017) suggested that the observed fluctuations in T_{core} are more so the result of underlying changes in progesterone and estradiol levels during pregnancy such that higher estrogen levels in later pregnancy augment vasodilation and heat dissipation resulting in a lower body temperature. In contrast to the hypothesis, the lack of difference shown here between gestational stages in the change in T_{tymp} resulting from exercise (Figure 8B) suggests that, despite the increase in H_{prod} , the exercise did not elicit greater thermal strain as pregnancy progressed. The combined findings of the present study provide strong support for previous work (Clapp, 1991; Jones et al., 1985; Larsson & Lindqvist, 2005) suggesting improved thermoregulation during pregnancy.

The present results show lower \bar{T}_{skin} at T2 and T3 at baseline rest compared to non-pregnant CON. The current findings are counterintuitive given the characteristic increase in plasma (Hyttén & Paintin, 1963) and stroke volume (Robson et al., 1988) during pregnancy as well as the expected increased drive for dry heat loss due to the drop in T_{core} (Lindqvist et al., 2003). In support of the current findings Herbert and colleagues observed an initial drop in limb blood flow in weeks 12-20 of pregnancy (Herbert, Banner, & Wakim, 1958) in comparison to control participants. Still, Herbert found that following the 20-week time point, limb blood flow responses increased beyond control levels as gestation continued. While possible explanations for their observations were not provided, \bar{T}_{skin} responses seen in the current study's CON participants may be attributed to variations in hormonal profiles associated with the menstrual cycle (Charkoudian et al., 2017) which have been shown to increase skin temperatures up to three degrees higher in the follicular phase relative to the luteal phase (Bartelink, Wollersheim, Theeuwes, van Duren, & Thien, 1990).

Conversely, the present findings show a 0.5°C increase in resting \bar{T}_{skin} between T2 and T3 (P=0.05) which has been well established in the literature (Burt, 1949; Herbert et al., 1958; Jones et al., 1985) and suggested to be a thermo-physiological response by the maternal system to the increasing fetoplacental metabolism (Jones et al., 1985). Not unlike T_{tymp} , despite the increase in H_{prod} over the course of exercise, no change in \bar{T}_{skin} was observed at CON and T2 and in fact, \bar{T}_{skin} decreased by 0.18°C at T3. While the decrease in \bar{T}_{skin} was unexpected, similar reductions in skin temperature have also been reported by Jones (1985) wherein women in the third-trimester experience a dip in \bar{T}_{skin} at the beginning of a moderate intensity exercise treadmill running protocol (Jones et al., 1985). In non-pregnant populations, a fall in \bar{T}_{skin} observed at the onset (Torii, Yamasaki, Mdt, & Nakayama, 1992) and throughout (Nakayama, Ohnuki, & Niwa, 1977) exercise has been attributed to vasoconstriction suggesting a greater drive for blood flow to active muscles rather than dry heat exchange. In line with the literature, in the context of pregnancy, a possible explanation for the drop in \bar{T}_{skin} during exercise may be a delay in the removal of reflex mediated vasoconstriction of skin vasculature. Given that the fetus is less susceptible to teratogenic effects later in pregnancy (relative to early pregnancy)(Shiota & Opitz, 1982), it is plausible that redistribution of plasma volume away from the fetus for thermoregulation, via increased skin blood flow, is not considered a high priority relative to the nutrient supply to the utero-placental unit. As a result, higher intensities of heat stress may be required to elicit the same response as earlier in pregnancy. Given that uterine blood flow was not measured in the present study, and that a similar \bar{T}_{skin} response has only been observed once before, further research examining \bar{T}_{skin} during exercise is necessary to establish and understand the mechanisms governing this response.

From the physiological responses to the exercise protocol it can be concluded that, as suggested through earlier literature, the maternal body exhibits protective thermoregulatory

responses that help preserve fetal homeostasis and allow for safe continuation of low to moderate-intensity PA throughout pregnancy despite the increasing heat load.

4.3 Perceptual Measures of Strain during Exercise Throughout Pregnancy

As described by Tucker's anticipatory feedback model (Tucker et al., 2006), the internal pathway to exercise continuation or termination is multidimensional and involves both physiological and perceptual cues. Based on this principle, this thesis sought to examine the influence of perceptual feedback to exercise in the pregnant population, and how these responses relate to physiological parameters. In accordance with the study hypothesis, as women progressed through pregnancy, their perception of physical exertion, as delineated through the BORG scale (Figure 9A), was greater for the same exercise stimulus suggesting increased physical load and possible biomechanical impedances in joint and body movement with gestation. Furthermore, correlation analysis indicated a strong relation and similar slopes between RPE and HR at all three participant groups (Figure 10) which suggest that perceptual sensation of exertion remained well aligned with the physiological indicator of exertion (HR) throughout pregnancy. The present findings defend those of Pivarnik (Pivarnik et al., 1991) and lend support to the concept that the BORG scale is an effective tool for assessing exertion limits in PA throughout pregnancy.

While an increase in perceived TS was anticipated as pregnancy progressed, what was not expected was that this response would persist despite the lack of change in T_{tymp} and \bar{T}_{skin} between the gestational conditions during exercise. This variance in the physiological and perceptual measures of heat strain suggests that the sensation of heat strain is not linked purely to the thermal parameters of T_{tymp} and \bar{T}_{skin} , but, like RPE, may also be influenced by efferent feedback from the cardiovascular system and changes in load. In line with this idea is the notion that a protective

perceptual mechanism may be in place to prevent the continuation of further exertion (PA) far before a physiological thermal strain is experienced by the pregnant female body.

As depicted in Figure 11 (A, B and C), a direct correlation exists between TS and T_{tymp} at all three participant groups: a response that has never been examined before in the pregnant population. The current findings are not supported by Kamon who found no relationship between TS and T_{core} (Kamon et al., 1974). The disparity between the present findings and those of Kamon is likely due to differences in study design. Whereas Kamon used ambient heat stress to elicit large perceptual change, heat stress was avoided in the present study to simulate a stable environment more closely representative of conditions in which pregnant women engage in PA. Therefore, due to the nature of homeostatic drive to tightly regulate core temperature, it is not surprising that Kamon did not observe a strong correlation between the large changes in perceptual measures (influenced by ambient temperatures) and the small fluctuations in core temperature measures (which were closely regulated by the body).

Finally, a strong negative correlation was observed between TS and \bar{T}_{skin} at T3 (Figure 11F), which was likely driven by the sharp drop in \bar{T}_{skin} (Figure 8C). While no previous work has examined this relationship in the pregnant population, the current findings contrast that of Kamon who identified that the two variables were correlated in male participants exercising in the heat (Kamon et al., 1974). In extension to Kamon's findings, recent evidence suggest that upper body skin temperature is a strong predictor of thermal comfort in a non-exercise state (Wu et al., 2017). Conversely, Liu *et al* (2014) observed that in hot environments, no correlation was found between TS and change in \bar{T}_{skin} resulting from increased ambient temperatures (Liu et al., 2014). In the context of exercise, \bar{T}_{skin} has also been suggested as irrelevant to measures of performance and pacing of aerobic exercise in normothermic or heated ambient conditions (Levels, de Koning,

Foster, & Daanen, 2012). Overall, while findings of the present study support the notion that TS is not a suitable indicator of \bar{T}_{skin} in the pregnant population, as shown by the available literature, our understanding of the relationship between \bar{T}_{skin} and TS is neither yet fully developed nor widely agreed upon. As such, further work is warranted to delineate \bar{T}_{skin} variability throughout pregnancy and its interactions with perceptual measures within diverse populations and environmental conditions.

4.3 Conclusion of the Thesis

The results of this study indicate that during the graded exercise protocol, pregnant females exhibit 7-8% more H_{prod} with each trimester of pregnancy. However, it is postulated that this increase in H_{prod} does not pose a thermoregulatory risk to the maternal or fetal system given the lack of physiological heat strain observed throughout gestation in response to the exercise task. The present findings support the notion that thermoregulatory responses improve in the pregnant state to promote an increased drive for heat loss. Moreover, this study provided support for the validity of the BORG scale as a psycho-physical tool for pregnant women exercising at light to moderate intensities. Finally, the present study was the first to explore the validity of the TS scale in the pregnant population. The study findings suggest that the TS scale can be an effective psycho-physical tool for assessing thermal strain (indicated by T_{tymp}) in response to exercise in the pregnant population under normothermic environmental conditions.

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Appendices

Appendix A: HALO Submaximal Protocol

DOB (MMM-YY): Age:	Height: Pre-instrumentation Weight:	Predicted HRmax: 85% HRmax:
Room Temp: _____ °C	Relative Humidity: _____ %	Air Pressure: _____ psi

iButton #:	Chest:	Bicep:	Thigh:	Calf:
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Time (min)	Test Time (sec)	Speed (mph)	Grade %	HR (bpm)	RPE		Tymp T°
					TS		
Resting and seated							
0-1							
1-2							
2-3							
3-4							
4-5							
5-6							
6-7							
7-8							
8-9							
9-10							
10-11							
11-12							
12-13							
13-14							
14-15							
15-16							
16-17							
17-18							
18-19							
19-20							

	Test	Speed	Grade	HR	RPE	Tymp T°
Time (min)	Time (sec)	(mph)	%	(bpm)	TS	
Begin walking						
Warm-up						
0-4	-4	2	0			
Commence Test						
4-7	30 (0:30)	2	2			
	60 (1:00)	2	2			
	90 (1:30)	2	2			
	120 (2:00)	2	2			
	150 (2:30)	2	2			
	180 (3:00)	2	2			
7-10	30 (0:30)	2	4			
	60 (1:00)	2	4			
	90 (1:30)	2	4			
	120 (2:00)	2	4			
	150 (2:30)	2	4			
	180 (3:00)	2	4			
10-13	30 (0:30)	2	6			
	60 (1:00)	2	6			
	90 (1:30)	2	6			
	120 (2:00)	2	6			
	150 (2:30)	2	6			
	180 (3:00)	2	6			
13-16	30 (0:30)	2	8			
	60 (1:00)	2	8			
	90 (1:30)	2	8			
	120 (2:00)	2	8			
	150 (2:30)	2	8			
	180 (3:00)	2	8			

16-19	30 (0:30)	2	10			
	60 (1:00)	2	10			
	90 (1:30)	2	10			
	120 (2:00)	2	10			
	150 (2:30)	2	10			
	180 (3:00)	2	10			
19-22	30 (0:30)	2	12			
	60 (1:00)	2	12			
	90 (1:30)	2	12			
	120 (2:00)	2	12			
	150 (2:30)	2	12			
	180 (3:00)	2	12			
22-25	30 (0:30)	2	14			
	60 (1:00)	2	14			
	90 (1:30)	2	14			
	120 (2:00)	2	14			
	150 (2:30)	2	14			
	180 (3:00)	2	14			
Rec.	0-1	1	0			
Rec.	1-2	1	0			

Comments:

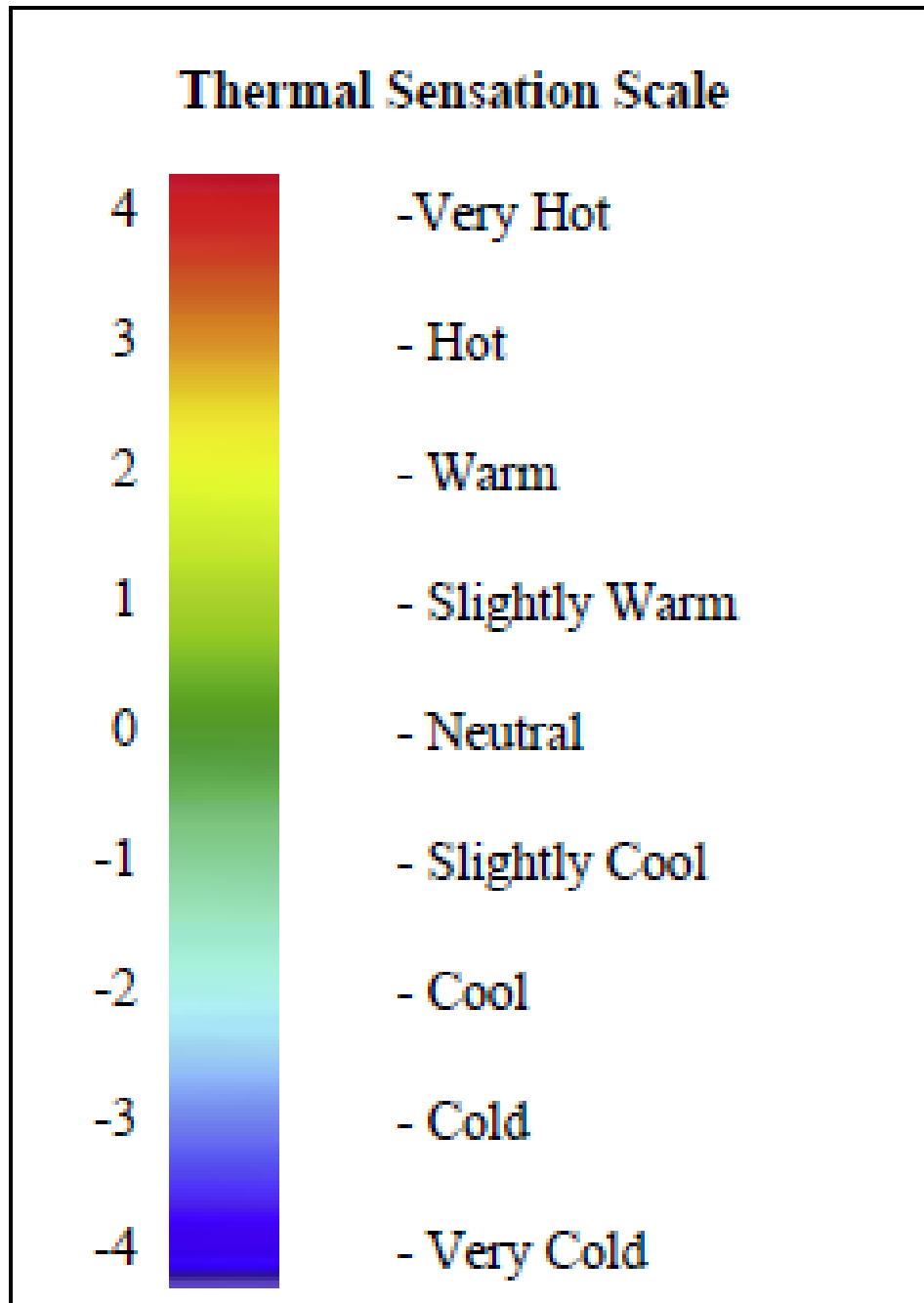
<p>Description of Clothing:</p> <hr/> <hr/>

Appendix B: BORG Scale

Rate of Perceived Exertion Scale

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

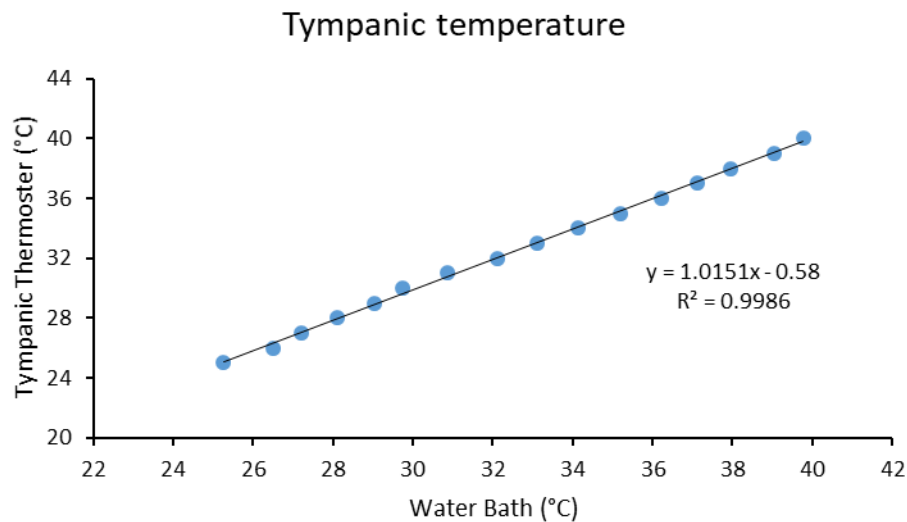
Appendix C: Thermal Sensation Scale



Appendix D: Validation of Systems

The tympanic thermometer used to measure tympanic temperature was validated using a water bath to assess accuracy of the thermometer's measures over a range of sub- to suprphysiological temperatures.

The result of the validation test is as follows:



Based on the findings of the validation test, I am confident of the accuracy in the temperature measuring capability of the tympanic thermistor. However, the placement of the thermistor into the ear canal of the participant and the inability to completely block the ear canal from room air, resulted in inaccuracy of the tympanic temperature measures. To correct for this shift in temperature resulting from ambient air in the ear canal, oral temperature measures were collected from the subjects at baseline resting. The difference of the oral and the tympanic temperatures were calculated and used as a correction factor for the tympanic temperature values.

Appendix E: Thermal Chamber Floor Plan

